Spatial and Temporal Variability in the Water Chemistry of Atlantic Salmon Rivers in Insular Newfoundland: An Assessment of Sensitivity to and Effects from Acidification and Implications for Resident Fish

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by

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ABSTRACT

Scruton, D. A. 1986. Spatial and temporal variability in the water chemistry of Atlantic salmon rivers in insular Newfoundland: an assessment of sensitivity to and effects from acidification and implications for resident fish. Can. Tech. Rep. Fish. Aquat. Sci. 1451: v + 143 p.

Twenty-two acid sensitive Atlantic salmon rivers were sampled monthly from May 1981 to May 1982 to evaluate susceptibility to, and effects from, acid deposition. Weighted mean pH of the rivers varied from 5.08 to 6.27, with 20 rivers demonstrating a mean annual pH of less than 6.00. All rivers demonstrated low mean alkalinities (10-64 $\mu eq\ L^{-1}$) reflecting the extreme sensitivity of the study rivers. Alkalinity deficits in the order of 42-105 $\mu eq\ L^{-1}$ were apparent. Rivers were moderately to highly coloured (mean colour values from 31 to 91). Non marine sulphate values ranged from 42.6 to 83.2 $\mu eq\ L^{-1}$, and were generally lower than those in high deposition regions of northeastern North America.

Depressions in pH in most systems were evident in both the late fall and in the spring. Annual pH minima were experienced on several rivers in the fall due to unusually high precipitation inputs while annual minima in the spring in relation to snow melt were evident on 13 rivers. Concurrent elevation of aluminum in association with pH depressions was not apparent. pH, alkalinity, base cations (Ca^{+2}, Mg^{+2}) and sodium varied inversely with the river hydrograph reflecting a dilution effect due to runoff. Sulphate and water colour (as a correlate organic influence) varied positively with the hydrograph reflecting the importance of precipitation as a source for sulphate and in the flushing of terrestrial organic reservoirs. The conclusion of this study is similar to those of others undertaken in the region, that is, that chronic acidification is not a widespread problem at present. pH excursions below 5.0 provide evidence of transient episodic acidification of sufficient magnitude to affect resident salmonids.

RÉSUMÉ

Scruton, D. A. 1986. Spatial and temporal variability in the water chemistry of Atlantic salmon rivers in insular Newfoundland: an assessment of sensitivity to and effects from acidification and implications for resident fish. Can. Tech. Rep. Fish. Aquat. Sci. 1451: v + 143 p.

Vingt-deux rivières à saumon de l'Atlantique sensibles à l'acidification ont fait l'objet, de mai 1981 à mai 1982, de prélèvements visant à évaluer leur sensibilité aux précipitations acides et les effets de ces dernières. Le pH moyen pondéré des cours d'eau a varié de 5,08 à 6,27 et le pH annuel moyen de 20 d'entre eux était inférieur à 6,00. Toutes les rivières présentaient un faible niveau d'alcalinité moyenne (10-64 $\mu eq\ L^{-1}$), ce qui dénote l'extrême sensibilité de ces cours d'eau. On a noté des déficits d'alcalinité de l'ordre de 42-105 $\mu eq\ L^{-1}$. La coloration de l'eau variait de modérée à élevée (valeur

moyenne de 31 à 91). Les concentrations de sulfates non marins variaient de 42,6 à 83,2 µeq L^{-1} et étaient généralement inférieures à celles notées dans les régions à fortes précipitations acides de la partie nord-est de l'Amérique du Nord.

On a noté une baisse du pH dans la plupart des réseaux vers la fin de l'automne et au printemps. Plusieurs rivières ont présenté un pH annuel minimum au cours de l'automne suite à des apports par précipitations anormalement élevés et l'on a noté, pour 13 rivières, des minimums annuels au printemps suite à la fonte des neiges. Il n'y a cependant pas eu d'augmentation de la teneur en aluminium correspondant aux baisses du pH. Les valeurs du pH, de l'alcalinité, des cations basiques (Ca^{+2} et Mg^{+2}) et du sodium variaient de façon inverse à la courbe d'écoulement de la rivière, ce qui indique un effet de dilution dû au ruissellement. Les teneurs en sulfates et la coloration de l'eau (dénotant l'influence des matières organiques) variaient positivement en fonction des courbes d'écoulements de la rivière, ce qui montre l'importance des précipitations en tant que source de sulfates et du lessivage des réservoirs organiques terrestres. La conclusion de la présente étude est semblable à celles d'autres études réalisées dans cette région; à savoir que l'acidification chronique ne constitue pas actuellement un problème généralisé. Les baisses du pH à des valeurs inférieures à 5,0 prouvent l'existence de périodes d'acidification provisoire suffisamment importantes pour affecter les salmonidés présents dans ces cours d'eau.

INTRODUCTION

The adverse effects of acid rain on freshwater fish habitat and fish communities are now well documented for many regions of the world. The acidification of freshwaters in Scandinavia has progressed to the point where fish populations in tens of thousands of lakes and many rivers are affected (Jensen and Snekvik 1972; Aylmer et al. 1984; Dickson 1975). Beamish and Harvey (1972) focused North American attention on the problem by documenting the decline in fish populations in the LaCloche Mountain lakes of Ontario in relation to coincident pH declines. Schofield (1976b) subsequently reported on the acidification of lakes in the Adirondack Mountain region of New York and the concurrent loss of brook trout populations. Watt et al. (1979) were the first to investigate the acidification problem in Atlantic Canada. A comparison of historical data with data collected 21 years later on some Halifax County lakes indicated pH declines that were attributable to local and anthropogenic effects.

The acidification phenomenon has seriously affected the lotic habitat of Atlantic salmon. Seven major salmon rivers in Norway are devoid of naturally reproducing salmon populations and the problem appears to be spreading to the west coast of the country (Lievestad et al. 1976). In Nova Scotia, nine former salmon rivers are extremely acid (pH < 4.7) and are unable to sustain natural reproduction. Another thirteen rivers appear to be experiencing significant declines in numbers of salmon attributable to acidification (Watt 1981). Research on New England salmon rivers has indicated that conditions on high order (fourth or fifth) streams are not critical for survival of the species, however, conditions in some headwater streams may be detrimental to salmon reproduction and subject to continued degradation (Haines and Akielaszek 1983). Studies on rivers on the Quebec North Shore have confirmed the sensitivity of these systems to acidification but have not documented conditions critical for survival of salmon (Brouard et al. 1982, 1983).

Atlantic salmon represent a very significant economic and cultural resource to the people of Newfoundland and Labrador (Taylor 1985). Approximately one sixth of the world's commercial salmon catch and 90% of Canada's catch are taken in provincial waters. Similarly the recreational fishery for salmon in Newfoundland accounts for about 50% of the total catch in Canada. These two fisheries contribute millions of dollars to the local economy (Chadwick et al. 1978). At present most salmon stocks in insular Newfoundland are self sustaining through natural reproduction. Over the last 20 years adult transfers, fishways, semi-natural rearing and fry stocking have been used successfully to expand the range of Atlantic salmon stocks. Presently a salmon enhancement (development) program has been initiated, with public/community involvement, to expand salmon stocks into previously unused or underutilized habitats (Pratt 1984). Recently the Provincial and Federal Governments have developed a fish hatchery for salmon to provide additional support for enhancement opportunities, particularly aquaculture. It is apparent there is considerable effort being expended to maintain and expand salmon stocks in the province of Newfoundland and Labrador.

In Canada, much of the Eastern provinces are receiving precipitation considerably more acid than normal clean rain (pH of 5.6). The Atlantic

Provinces lie in the mid-Atlantic westerlies, a pattern of prevailing winds which results in the region being immediately downwind of most of North America's major pollution sources. The Province of Newfoundland and Labrador lies on the eastern extreme of this zone. Despite being thousands of kilometers removed from major industrial centres in North America, the province is receiving acid precipitation in the range of pH 4.5 to 4.9 (from 5 to 12x more acid than clean rain) (Bangay and Riordan 1983). There is no clear evidence of a gradient in deposition in a N/S or E/W direction; however, it is likely the southwest corner of the province is receiving the most acid precipitation (pH ~ 4.5) while the northeast corner the least acid (pH ~ 4.9). The south central region and the Avalon Peninsula are likely receiving precipitation in the range of pH 4.5 to 4.7. Longer term data records suggest considerable variation in precipitation acidity and in total acid deposition from year to year.

Deposition of sulphate, widely used as the standard for interregional comparison of acid deposition rates, ranges from about 10 to 40 kg/ha/yr in eastern Canada and, in Newfoundland, from 10 to 20 kg/ha/yr (Whelpdale 1978; Harvey et al. 1981). Researchers have established that deposition in the order of 20 kg/ha/yr of SO_4^{2}) or greater is sufficient to seriously threaten sensitive freshwaters (Bangay and Riordan 1983) and recently, acidification of lakes and rivers has been documented at even river rates of deposition (~15 kg/ha/yr of SO_4^{2}). Total annual precipitation on the island ranges from 850 to 1750 mm and annual runoff from 600 to 2100 mm (Yoxall 1980). Precipitation in Newfoundland can be from 1.5 to 2.0 times the amount received in central regions receiving highly acid precipitation (Ontario and Quebec) and can act to narrow the gap in relative loadings.

Future trends in acid causing emissions and resulting deposition levels are difficult to forecast. Downturns in the North American economies have slowed the rate of growth in emissions since 1972-73, and in addition, there has been a committment to reduce sulphur emissions in Eastern Canada by 25% to the year 1990, and a further 25% to the year 1994. Conversely there is a continued trend to reliance on coal fired electrical generation in North America. Of particular concern to Newfoundland is the conversion to coal fired electrical generation in Nova Scotia, particularly in association with the Lingan Plant on Cape Breton Island. Emissions from this facility are expected to be transported directly to the sensitive south coast region of the island.

The potential impact of acidic deposition is dependent on the susceptibility of the region and its freshwaters which is primarily governed by the composition of underlying soils and bedrock. Insular Newfoundland, despite its geologic heterogeneity, is characterized (on the basis of bedrock geology) as having extensive areas that are highly sensitive to potential acidification (Schilts 1981). Recent lake survey efforts (Clair 1981; Scruton 1983) have confirmed the low buffering ability of much of insular Newfoundland's freshwaters. The province is also dominated by extensive areas of organic deposits, having in excess of 2 million hectares of peatlands. These organic deposits are widely distributed and can amount to 25-30% of the land types in many of the major river watersheds (Northland Associates 1982). Surface waters reflect the occurrence of organic deposits in that they are highly coloured and demonstrate a natural acidity (Scruton 1983).

Owing to the value of the salmon resource in Newfoundland and the documentation of acidification of rivers in neighbouring Nova Scotia, a survey was warranted to assess the current status of representative salmon rivers on the island in relation to acid deposition and to determine the susceptability of these systems to the effects of continued acid loading. The survey was conducted on a monthly basis to evaluate seasonal variability, specificially to examine for periods (episodes) of low pH that could adversely effect reproduction and recruitment of resident salmonids.

DEPARTMENTAL PROGRAM AND OBJECTIVES

The Department of Fisheries and Oceans has undertaken, since 1980, a departmental program on acid precipitation. The ultimate goal of this program is to protect freshwater and anadromous fisheries resources threatened by acid precipitation and related pollutants, and to ensure the long-term maintenance of social and economic benefits associated with this resource.

The Department initially recognized the need to establish a comprehensive data base, comparable within Canada, for a number of lakes and rivers in sensitive terrain, as a means of overcoming the deficiencies in knowledge of regional responses to acid deposition. In 1981, the Department initiated a National Inventory Survey program (or N.I.S.) to obtain a comprehensive data base for a number of lakes and rivers to evaluate the regional implications of acid deposition. Large scale lake inventory programs have been undertaken in the provinces of Ontario, Quebec, Nova Scotia, New Brunswick, and in insular Newfoundland (1981) and Labrador (1982). Similarly, river inventory (or monitoring) programs have been undertaken in Quebec, Nova Scotia, insular Newfoundland (1981-1984) and Labrador (1982-1984). These regions are all characterized as having important Atlantic salmon producing rivers draining acid sensitive bedrock.

These programs have emphasized common study elements, the utilization of common sampling techniques, and quality control to permit an inter-regional evaluation of the acidification problem. The river inventory program was also conceived to provide a temporal component to permit the evaluation of seasonal variability in key parameters.

The primary objective of the National Inventory Survey was to establish a data base that would permit an inter- and intra-regional evaluation of the susceptability and status of lakes, rivers, and resident biota in relation to acid deposition. A second objective was to aid in understanding the processes governing susceptability to provide a basis for prediction of the potential future impacts at projected levels of deposition. Thirdly, this inventory was to provide a comprehensive and well-defined data base that would lend itself to future monitoring programs.

MATERIALS AND METHODS

RIVER SELECTION

Initially, 45 major river systems were selected for monthly sampling of water chemistry. After the initial three months of survey (May 1981 to July 1981) the number of study systems designated for continuing study was necessarily curtailed to 22 rivers, (24 sites) on the basis of sensitivity to potential acidification and accessibility during the winter months. For the most part, rivers selected for continuing study drained primarily bedrock of moderate to high sensitivity to potential acidification (Schilts 1981). Fig. 1 identifies the watershed boundaries of the study rivers and the sampling sites, and other watershed characteristics are contained in Appendix 2, Table 2.1. Rivers that were selected for study were those that were known to have good existing runs of Atlantic salmon (Porter et al. 1974), acknowledged to contain good potential to produce Atlantic salmon (habitat is inaccessible or accessible habitat is underutilized) (Atlantic Salmon Task Force 1978), or were rivers that have been identified as having opportunities for enhancement of existing fish stocks (Pratt 1984).

Study rivers were generally distributed across the island. No rivers were selected for long-term study on the western margin of the island due to the occurrence of non acid-sensitive bedrock in that region. By region, two systems were selected on the Northern Peninsula (Cloud River, Northwest River), two in the Central Region (Badger River, Noel Paul's River) six in the Eastern Region (Gander River, Ragged Harbour River, Indian Bay Brook, Gambo River, Terra Nova River, Southwest River), three on the Avalon Peninsula (Biscay Bay (Back) Brook, Colinet River, Rocky River), and nine rivers along the south coast of the island (Pipers Hole River, Long Harbour River, Baie du Nord River, Conne River, Baie D'Espoir Brook, Dolland Brook, Grey River, White Bear River, LaPoile River). Three sites were selected on the Conne River to examine the sensitivity of two major tributaries relative to the mainstem. Rivers selected for study also represented all three major size groupings identified for insular Newfoundland. Thirteen study systems are considered short rivers (<64 km), eight rivers are considered of intermediate length (64-161 km), while one system, the Gander River, represented one of three large river systems (>161 km in length) in insular Newfoundland (MacPherson and MacPherson 1982).

Rivers were routinely accessed by Bell Jet Ranger 206B helicopter (South Coast systems), by road (Central, Eastern, and Avalon systems) and by boat or skidoo (Northern Peninsula systems). Generally, the water sample was obtained either mid-river (helicopter sampling only) or along the river bank near the mouth of the river, at least 1 km above any tidal influence, so as to obtain a sample that would reflect the entire primary drainage area. Samples collected by road, however, were not always obtained near the river mouth, but generally reflected about 90% of the drainage system (the minimum being about 75% for the Gander River).

Samples were collected at monthly intervals over a 13-month period from May 1981 to May 1982. On several occasions (on the south coast), samples were not collected due to poor weather preventing helicopter access. Samples were

not collected from the Cloud and Northwest Rivers (Northern Peninsula) in January, February and May 1982 due to treacherous conditions during freeze up and spring breakup of these systems.

WATER SAMPLE COLLECTION

Samples for Gran alkalinity and field pH were collected in 250 ml linear polyethylene (LPE) Nalgene bottles while a 1 L LPE Nalgene bottle was filled for subsequent major ion analysis. A 125 ml LPE Nalgene bottle, pre-acidified with 2 ml of nitric acid prior to field collection, was used to collect the sample for trace metals analysis. All LPE Nalgene bottles were stored chilled until analyses of field measured parameters or until samples could be transported to the analytical laboratory. Samples for ortho-PO_4^{-}, NO_3^{-}, Cl^{-} and SO_4^{2} were frozen in LPE scintillation vials (20 ml) upon arrival at the analytical laboratory.

Samples for the determination of dissolved gases (CO_2 and O_2) were collected in 300 ml Biochemical Oxygen Demand glass bottles. Samples for CO_2 analysis were kept cool (no additional preservation) until analyzed. The dissolved oxygen sample was preserved in the field with the addition of 1 ml of manganous sulphate and 1 ml of alkaline iodide, then stoppered and shaken. A second mixing was performed prior to storage.

FIELD WATER CHEMISTRY

River water samples were routinely analyzed for pH, dissolved carbon dioxide (CO_2), dissolved oxygen (O_2) and alkalinity within 48 hours of collection. A Metrohm model 1151 portable pH meter, accurate to 0.01 pH unit, and with a combination glass/reference electrode, was used for all field measurements of pH and for potentiometric titrations.

Samples for alkalinity determination were stored, cooled, and then warmed to room temperature for analysis by field personnel, routinely within 24 hours of collection. The analytical laboratory performed titrations on water samples collected from Avalon, Central and Eastern rivers, usually within 48 hours of collection. The titrimetric procedure for Gran analysis is as described by the Ontario Ministry of Natural Resources (1980). Total inflection point alkalinity was later calculated from the data set obtained by the Gran titration according to a modified computer routine (after Kramer 1978). The initial pH reading obtained in each titration was taken as the field pH for that sample.

Samples for free carbon dioxide determination were kept cool and in the dark, and were analyzed within 24 hours of collection. Free CO_2 was determined by potentiometric titration of a 100 ml sample with sodium carbonate to a fixed end point of pH 8.3, using method 407B as described by American Public Health Association et al. (1975).

Samples for determination of dissolved oxygen, once fixed, were stored chilled prior to analysis. Determination of the dissolved oxygen content was

carried out using the standard Winkler titration as described by the American Public Health Association et al. (1975), method 218A.

LABORATORY ANALYSIS OF WATER SAMPLES

One liter water samples for major ion and nutrient analyses, and 125 ml acidified samples for heavy metal determinations, were returned to the analytical laboratory in St. John's, Newfoundland. A total of 294 samples were analyzed for 16 separate parameters, and several additional parameters were calculated. Eight heavy metals were determined during the first three months of sample collection, but this was curtailed due to high costs and the fact that many ambient metal levels were below the limits of detection. Analyses of total aluminum was resumed during the suspected high discharge period of March, April and May 1982. Dissolved organic carbon (DOC) was also measured during these months. A list of the analytical procedures used to determine all water sample parameters and the limits of detection is provided in Table 1. All laboratory analyses followed methods outlined in Environment Canada (1979) and the American Public Health Association et al. (1975).

Excess or non-marine concentrations of sulphate, calcium, magnesium, sodium and potassium were calculated using the equations in Thompson (1982), based on the ratio of these ions to chloride in sea water and the measured concentration of chloride in each sample.

The sum of anions (SO_4^{-2}, Cl^-, HCO_3^-) and cations (Ca^{+2}, Mg^{+2}, Na^+, K^+ as $\mu eq\ L^{-1}$), percent difference, and sum of constituents (as mgL^{-1}) were calculated as a check on analytical quality. A percent difference or percent error of ± 20% was considered the upper limit for acceptability (after Environment Canada 1979):

$$\text{Percent difference (error)} = \frac{\Sigma \text{ cations} - \Sigma \text{ anions}}{\Sigma \text{ cations} + \Sigma \text{ anions}} \times 100 \qquad (1)$$

An Environmental Protection Association standard reference sample and two blind batches of water samples (five each) were also analyzed by the participating lab to permit an interlab comparison of data.

DATA TREATMENT

The analytical data for each sample for the 22 river systems (24 sites) is contained in Appendix 1, Tables 1.1 and 1.2. Mean values for each parameter were calculated from single sample data for the 13-month period of record. Simple arithmetic means were calculated treating each sample equally. Volume-weighted means, adjusted according to discharge, were also determined from the following equation:

$$\bar{X} = \frac{\sum_{i=1}^{N} X_i D_i}{\sum_{i=1}^{N} D_i} \qquad (2)$$

where:

$\bar{X}$ = volume-weighted mean concentration of parameter
X_i = concentration of parameter on sampling date (i)
D_i = daily discharge (recorded or extrapolated) for river on sampling date (i)
N = number of samples collected per river.

Mean values (arithmetic and volume-weighted) are contained in Appendix 1, Tables 1.1 and 1.2 and volume-weighted mean data have been summarized in Table 2. Volume weighted mean data have also been used in all evaluations of spatial differences in water chemistry, and in assessment of sensitivity and current status with respect to acid precipitation. Weighting the data according to discharge is considered a valid approach for lotic systems but it is recognized that this calculation will strongly emphasize the composition of water during high flow periods (Hem 1970).

All hydrological data used in this report were provided by Environment Canada, Inland Waters Directorate, Water Survey of Canada (WSC). Hydrometric data used includes daily mean discharge (m^3S^{-1}) for the sampling date, total annual discharge (cubic decameters), and the hydrograph for the period of record (May 1981 to May 1982). Details on the hydrometric survey operations of the Water Survey of Canada are contained in Environment Canada (1980). Of the 22 river systems selected for study, 8 are unregulated and gauged by WSC and discharge data was readily available. Grey River is also gauged but the hydrological record for the study period was incomplete and therefore not used. For the other 13 rivers, flow data was extrapolated from the nearest (geographically) unregulated and gauged system. Since variation in discharge through time was of interest and not variation between study rivers, extrapolated data was not adjusted for differences in drainage area, watershed slope, runoff, retention time, etc.

BIOPHYSICAL CHARACTERIZATION OF RIVER WATERSHEDS

The biophysical character of each of the 22 study rivers was determined based on systematic stratification of the land surface into ecologically significant segments of the terrestrial and aquatic environment. The ecodistrict level of differentiation (second level of biophysical mapping) was used. River watershed boundaries were superimposed on an ecodistrict map of the island of Newfoundland (Northland Associates 1982). The proportion of each land class area (productive forest, softwood scrubs, organics, etc.) were then determined based on the proportions of each land class in the ecodistrict and the proportion of each ecodistrict within the watershed boundary. This approximation assumes an even distribution of land class types across each ecodistrict. The proportional representation of each land class type in each study river has been summarized in Appendix 2, Table 2.2.

QUALITY ASSURANCE

A preliminary check on the accuracy of the water chemistry determinations was made by comparing the sum of cations and the sum of anions in calculation of percent difference or percent error (see Equation 1). The log:log (base 10) correlation between cations and anions was very highly significant ($P \leq 0.001$) for total ions ($r^2 = 0.86$; $n = 292$) and sea salt corrected ions ($r^2 = 0.84$, $n = 290$). A total of seven samples (2%) had a percent difference of greater than 20% and 21 samples (7%) a percent difference in excess of 15%. Considering the dilute nature of study rivers and strong marine influence, this is considered acceptable although it does point to potential analytical errors in some samples.

Laboratory and field measures of pH and alkalinity were also compared. Regressions were very highly significant ($P \leq 0.001$) but regression coefficients were considered poor ($r^2 = 0.69$, $n = 151$, for lab pH vs field pH, $n = 268$, $r^2 = 0.65$ for log of lab alkalinity vs log field alkalinity). The reasons for poor comparability between lab and field measurements for these two parameters is unclear. A comparison of lab to field measured pH revealed that lab measured values were consistently lower than field measured values. It was subsequently learned that lab pH was often not measured for several months after collection, and the sample could be stored at room temperature for several weeks. It is likely that dissolution of CO_2 and biodegradation of particulate organic matter may have contributed to lower pH values in the lab.

In addition the contracted laboratory has participated in inter-laboratory comparisons as coordinated by Quality Assurance and Methods Section of Environment Canada, Burlington, Ontario. Results indicate a low bias for sulphate, chloride, pH, alkalinity, and conductivity and high bias for nitrate/nitrite. The laboratory performance is considered moderate with respect to other labs participating in the comparison study. In addition, detection limits for chloride and sulphate are relatively high (0.2 and 1.0 ppm, respectively) and biases in those parameters will significantly alter results. Biases in chloride data will also affect the calculation of non-marine ion concentrations. It is further acknowledged that sulphate, as determined by the methyl thymol blue (MTB) method, is subject to colourmetric interference, which may lead to overestimation in highly coloured waters (Kerekes and Pollock 1983). This will be considered when evaluating the sulphate data for the study systems.

Volume-weighted mean data for each river was used to compare non-marine cations minus bicarbonate to non-marine sulphate as an additional check on data quality (see Fig. 2). In all cases, the comparison yielded an excess of cations indicating either an overestimation of cations, poor sea salt correction, or an additional major anionic constituent. Recently, Kerekes (1983) have suggested that, in highly coloured waters, organic acids be included as an anion ($COOH^-$) in computing ion balances. Organic anions were computed from pH and dissolved organic carbon (DOC) according to Oliver et al. (1983) for the last three months of study. However, DOC was not routinely measured during this study and $COOH^-$ could not be incorporated into the anionic sum and ion balance of all samples. Recently this approach has been adopted as

routine procedure in survey efforts in Newfoundland and the result has been greatly improved ion balances (a survey of 150 water bodies in 1984 yielded only 1 sample with a percent difference of greater than 10%, DFO unpubl. data.)

RESULTS AND DISCUSSION

RIVER WATER CHEMISTRY - SPATIAL ASSESSMENT

It should initially be noted that sampling sites were located to obtain samples that would reflect the majority of the entire primary drainage for each major river. As a general rule low order streams acidify to a greater extent and more rapidly than downstream reaches, just as headwater lakes are acidified before higher order lakes (Potter et al. 1982). A gradient in sensitivity as related to drainage order has been demonstrated by several authors (Johnson et al. 1969; Zimmerman and Harvey 1979; Brouard et al. 1983), and an increase in buffering capacity (alkalinity) is expected as a stream enlarges. It follows that data collected in this study would represent an average condition for the myriad of lower order tributary streams in the drainage systems of each study river. It is likely that some of the lower order headwater streams, often where much of the available salmonid spawning and rearing habitat is located, may be more sensitive to, and demonstrate greater effects from, acidification.

It is also more difficult to assess the impacts of acid deposition on lotic systems as there is a much wider gradient of physical and chemical conditions to consider than for one lake and its watershed. The major component of this gradient in conditions is the geological heterogeneity found in many of the watersheds. For example one study river, the Gander River, drains 6398 km^2 and contains seven major geological formations while, in a survey of 109 headwater lakes in 1981 (Scruton 1983), the largest drainage area surveyed was 137 km^2 with a maximum of two geological types occurring in any one watershed (Appendix 2, Table 2.1).

Surface waters which drain bedrock with different capacities to reduce acidity will reflect the character of the most reactive (dissoluble) bedrock. The most striking example of this are rivers on the Northern Peninsula draining into the Gulf of St. Lawrence. Many rivers have their headwaters in the major gneitic and granitic batholyth of the Long Range Mountains, while the lower reaches drain major limestone and dolomite deposits. The water chemistry of the headwaters (pH ~ 5.20, aklalinity ~ 5-10 $\mu eq\ L^{-1}$) is in sharp contrast to that of the lower reaches (pH ~ 7.25, alkalinity ~ 600 $\mu eq\ L^{-1}$) (data for River of Ponds from Scruton 1984b; ShawMont 1982). A sample obtained near the river mouth gives no evidence of the extreme acidity of the headwaters. Major rivers characterized as insensitive to the effects of acid precipitation may be comprised of tributaries of varying sensitivities to acid inputs.

It should be noted that data examined in this report represents both weighted means (by discharge), used for comparison between systems (spatial), and simple "point in time" sample data used in evaluating temporal trends and episodic effects. While monthly sampling and weighting the data should improve the reliability of the mean data, the same may not be true for assessing

variability through time. Many chemical parameters vary with stream discharge (Hem 1970; Gower 1980) with wide fluctuations possible, while accumulated pollutants in the snowpack are released early in snowmelt and not necessarily at maximum discharge (Johannessen et al. 1980). Our ability to assess the magnitude of episodes and short-term acidification will depend on when the sample was taken in relation to the hydrological cycle of each river. More frequent sampling (weekly or daily) duing peaks in the hydrological cycle would be required to determine the timing, magnitude and duration of these short-term effects. Unfortunately, the hydrological cycle in many insular Newfoundland Rivers is not consistent with respect to timing from year to year. This, coupled with the difficulty of sampling during high flow periods and the fact that the most sensitive study systems are remote (aircraft accessible), makes it difficult (and expensive) to mount a more intensive sampling program.

Hem (1970) considers that a single grab sample ought to be considered to represent the chemical composition for a few hours to a few days. Clair (pers. comm.) has monitored the water chemistry of a Nova Scotian river (Mersey R.) daily for a period of one year, and found that day to day, or week to week, changes can be dramatic. Rivers are, by nature, dynamic systems and kinetic processes may appear to dominate steady state equilibrium in water chemistry (Hem 1970). When trying to relate water quality parameters to temporal trends (and hydrological changes), interactions can become complex because all aspects of the hydrological cycle, over the gradient of conditions in the watershed, are involved.

Major Constituents

The relative proportion of major cations and anions in river chemistry varies considerably and reflects several major contributions including: geochemical weathering of underlying bedrock and associated overburden, deposition of marine aerosols, atmospheric inputs of anthropogenic pollutants, and input of dissolved organic constituents largely of terrestrial origin.

The relative contribution of each of these factors is related to the intensity of each factor and can be considered a dynamic interaction of acids and bases. Atmospheric inputs of seawater salts are supplying all of the chloride ion and much of the sodium ion to surface waters in Newfoundland (Kerekes and Hartwell 1980; Scruton 1983) while anthopogenic sources are implicated in supplying much of the sulphate and, to a lesser extent, nitrate and ammonium ions, with associated hydrogen ions, present in dilute surface waters (Harvey et al. 1981; Wright and Henriksen 1978). Carbonic acid weathering (with possible enhancement by mineral acids) of the lithological components is considered to supply most of the calcium, magnesium and bicarbonate ions (Hem 1970). Terrestrial contribution of dissolved or particulate organics are a major consideration of insular Newfoundland's freshwaters and can be inferred indirectly from water colour and directly from DOC measurements.

The sum of constituents or salinity of the river systems ranged from 8.20 to 21.80 mg L^{-1} (mean of 13.44) (Appendix 1, Table 1.1). These values are very low by global standards (world average is 112 mg L^{-1}, Livingstone 1963) but

similar to those reported from soft waters on the Canadian Shield (Armstrong and Schindler et al. 1971; Harvey et al. 1981). The proportion of marine ions contributing to the sum of constituents ranged from 27 to 62% (mean of 49%) on an equivalent basis and this must be also considered when comparing salinities between maritime and continental regions.

Marine Contributions

It is important to evaluate the contribution of marine aerosols to freshwater chemistry in the study rivers. A regional survey of Newfoundland lakes in 1981 (Scruton 1983) demonstrated that deposition of marine ions was considerable with all of the chloride (assumed) and over half of the ionic contribution of sodium and potassium in lakes originating as marine aerosols. There were significant contributions of sulphate (26%) and magnesium (12%) as well. A comparison of the proportional contribution of the five major ions contributed by aerosol deposition of sea salts between this data set and 109 insular Newfoundland lakes sampled in 1981 is contained in Table 3.

The contribution of ions of marine origin to the river data set is also considerable, and not surprising considering the sampling locations. Most river systems were sampled just above their confluence with salt water. The deposition of marine aerosols is considered to demonstrate a sharp coastal gradient with modification by precipitation, wind patterns and topography (Henriksen and Wright 1977; Wright et al. 1977). This situation was also evident in insular Newfoundland lakes sampled in 1981 (Scruton 1982). Ogden (1982) has suggested that about 80% of aerosol deposition in Nova Scotia occurs within 20 km of the coast. However, samples collected in this study would be expected to reflect an average condition for the entire watershed, rather than the sampling location itself. Indeed, some near coastal lakes (within 10 km or less of saltwater) sampled in 1981 (Scruton 1983) and in 1983 (unpublished data) demonstrated higher contributions of sea salts than did the river data (often sampled within 1 km of salt water). There is higher proportional contribution of sodium, sulphate, magnesium and calcium ions in the river data while potassium demonstrates higher marine contribution in the lake data (possibly an artifact of different detection limits provided by the laboratories in each study). The dilute nature of the study systems and the fact that no part of insular Newfoundland is greater than 100 km from saltwater is exemplified in the proportional contribution of marine ions.

Examining the marine influence on a river by river basis there is evidence of the influence of watershed orientation, distance from the coast, and meteorological patterns. Weather patterns are predominantly westerly or southwesterly with some seasonal modifications (MacPherson and MacPherson 1982). Not surprisingly the dilute, coastal Avalon Peninsula rivers, with very small watersheds and surrounded by salt water, showed the greatest proportional contribution of marine ions (averaging 58%). Rivers in the center at the Island demonstrated the lowest proportional contributions (41%, $n = 5$) with Noel Paul's Brook, demonstrating the lowest (27%). Marine contribution of dissolved constituents varied from 27 to 62% (mean of 49%).

It is important to examine (and extract) the marine influence on freshwater chemistry in insular Newfoundland so that the data base can be compared equally to continental data and true anthropogenic influences can be evaluated (Wright and Gjessing 1976). Thompson (1982a) has demonstrated the influence of sea salts in modifying the process of geochemical weathering in a Newfoundland river (Isle aux Morts River), which will also effect interpretation. Christophersen et al. (1982) have demonstrated short term acidification of coastal watersheds in Norway due to ion exchange of marine sodium for hydrogen ion (H^+) in acid soils. They concluded that this phenomenon was transient (short-term) and of minor importance relative to atmospheric deposition of acids. Sea salts therefore contribute dissolved constituents to freshwaters and may alter, in near-coastal systems, the normal process of geochemical weathering. In watersheds with acid soils, sea salts may make a minor, seasonal contribution to acidification through ion exchange.

Cations

The contribution of ions of marine origin is also apparent in the order of cationic dominance. Eighteen (twenty sites) were sodium dominated, in the order of Na > Ca > Mg > K, while the remaining four rivers were calcium dominated (Ca > Na > Mg > K). Extracting the marine contributions, the order of cationic dominance is more typical of soft continental freshwaters (Armstrong and Schindler 1971) with 20 rivers (22 sites) being calcium dominated (11 in the order Ca > Mg > Na > K, and 11 in the order Ca > Na > Mg > K). One river demonstrated non-marine sodium dominance (Na > Ca > Mg > K) and one river non-marine magnesium dominance (Mg > Ca > Na > K).

The order of non-marine cationic dominance is fairly typical for Newfoundland soft waters (Scruton 1983, 1984b; Kerekes and Swinghammer 1975; Jamieson 1974a and b) and is considered to demonstrate the proportional availability (weatherability) of these ions in surficial geological deposits. Ragged Harbour River demonstrates a slight magnesium dominance over calcium likely due to diorite deposits (high in magnesium content) in the watershed. Sodium dominance in the Biscay Bay (Back) River would suggest either an abundance of sodium aluminum silicates in the sedimentary deposits in the watershed or perhaps insufficient sea salt correction for sodium. Thompson (1982a) has demonstrated ion exchange of sodium for calcium in the Isle aux Mort River driven by seasalt, as evidenced by negative values for non-marine sodium associated with unusually high calcium values. Certainly this type of ion exchange reaction could be occurring in many soft water coastal watersheds. Sea salt inputs may alter the normal paragenetic sequence in geochemical weathering.

Calcium and magnesium are the principle cationic products of geochemical weathering and provide some measure of its rate. Weighted mean values for excess calcium and magnesium varied from 35 to 91 $\mu eq\ L^{-1}$ (mean of 62) and from 14 to 63 $\mu eq\ L^{-1}$ (mean of 33), respectively (Table 2). Calcium and magnesium are commonly associated in freshwaters and the non-marine concentrations of these ions were very highly significantly correlated ($r^2 = 0.63$, $n = 294$,

$P \leq 0.001$) in the study rivers. Calcium was dominant to magnesium in all but one river with the Ca:Mg ratio ranging from 0.95 to 3.05 (mean of 2.06).

Freshwaters with calcium concentrations of less than 200 $\mu eq\ L^{-1}$ are considered highly sensitive to potential acidification and this includes all of the study rivers. Calcium (and magnesium) concentrations are considered to best exemplify the neutralizing capacity of a watershed under normal carbonic acid weathering (rainfall pH ~ 5.6), not considering the influences of organic deposits. Some watershed studies have indicated the rate of geochemical weathering is accelerated by strong acid precipitation and hence base cation levels can be elevated (Henriksen 1982c, Harvey et al. 1981). However, Watt et al. (1979) did not demonstrate this for some Halifax county lakes in Nova Scotia.

The non-marine (excess) concentrations of sodium (weighted means) varied from 22 to 79 $\mu eq\ L^{-1}$ (mean of 37). Non-marine sodium was very highly significantly correlated to excess calcium ($r^2 = 0.26$, $n = 292$, $P \leq 0.001$) and magnesium ($r^2 = 0.46$, $n = 292$, $P \leq 0.001$) suggesting a significant geological source for the ion. The fact that non-marine sodium was more abundant than non marine magnesium at 12 sites is surprising and not consistent with previous lake survey data (Scruton 1983). The sedimentary geotypes, with associated sodium silicates, were not well sampled in the lake study (7% of lake watersheds) while these geological formations are major contributors to ten river watersheds and minor contributors to an additional four river watersheds.

Non-marine potassium levels (weighted means) were low, varying from 1.7 to 9.3 $\mu eq\ L^{-1}$ (mean of 3.5) (Table 2) and were very highly significantly correlated to excess calcium ($r^2 = 0.36$, $n = 294$, $P \leq 0.001$) and excess magnesium ($r^2 = 0.21$, $n = 294$, $P \leq 0.001$) suggesting similar geochemical sources. Potassium is often incorporated into stable minerals (clays) and may not be as readily soluble as other cations (Hem 1970).

Anions

Chloride was the dominant anion in all 22 rivers (24 sites). This is not surprising considering the significant marine contribution, the low buffering ability of the study rivers, and the relatively low levels of anthropogenic sulphate deposition. Twenty-two sites have an anionic dominance in the order of $Cl > SO_4 > HCO_3$ while two systems demonstrate an order of $Cl > HCO_3 > SO_4$. Considering non-marine ions only, sulphate is dominant to bicarbonate on 18 rivers (20 sites), with the order reversed for 4 rivers.

Comparatively, lakes on the island are chloride dominated if underlain by geotypes poor in readily available cations and bicarbonate and are bicarbonate dominated in the readily weathered geotypes (limestones, gabbros, etc.) (Scruton 1983). Northwest River with limestone deposits and Badger River and Noel Paul's Brook draining primarily sedimentary geotypes (with possible limestone or metamorphic equivalents) demonstrate the highest levels of HCO_3^-, Ca^{+2} and Mg^{+2}; the three principle ions originating from geochemical weathering. Road salt may be contributing to observed chloride levels in the

study rivers, but none of the systems have extensive road networks associated with their watersheds. The possible contribution of road salts would be more apparent in the seasonal pattern of chloride availability.

Sulphate values (weighted mean) for the 24 study systems ranged from 42.6 to 83.2 $\mu eq\ L^{-1}$ (mean of 59.32) while non-marine sulphate values (weighted mean) ranged from 27.8 to 65.1 $\mu eq\ L^{-1}$ (mean of 43.3) (Table 2, Fig. 3). These levels are similar to those previously reported for Newfoundland freshwaters (Scruton 1983; Clair 1981; Kerekes 1978). A survey of 109 lakes in insular Newfoundland in 1981 found excess sulphate to range from 5.7 to 91.4 $\mu eq\ L^{-1}$ (mean of 43.5 $\mu eq\ L^{-1}$) and 81% of the lakes had values ranging from 20 to 50 $\mu eq\ L^{-1}$ (Scruton 1983). Mean values for river data are higher than for the lake data set (43.3 vs 34.5 $\mu eq\ L^{-1}$), and may reflect the fact that weighted mean data for the rivers would incorporate the seasonal dynamics of sulphate availability.

High sulphate values (or anomalies) in several headwater lakes were suggested to be evidence of geological sources for the ion such as pyrite and/or gypsum (Scruton 1983). Two of these lakes were located in the headwaters of the Gander River, and have not appeared to have influenced the sulphate levels for the entire drainage system. Geological deposits of sulphur are considered small and localized and while they may readily influence the chemistry of one lake-one watershed, their contribution to a major drainage system the size of the Gander River (6398 km^2) is minimal.

Excess sulphate cannot be assumed to be all of anthropogenic origin. In addition to potential geological sources, natural background levels of sulphate of biological origin may exist, possibly as high as 60 $\mu eq\ L^{-1}$ (Harvey et al. 1981; Alymer et al. 1974). Research has also suggested that organic deposits may act as reservoirs (sulphate reduction to sulphur) and at certain times of the year sulphur is oxidized to sulphate and transported to receiving waters. Sulphate is taken up deep in bogs (above the water table) and is released after extensive dry periods when the water table is reduced (Urban and Bayley 1985). Recently considerable attention has been paid to the MTB method (colourmetric) of determination of sulphate. It is acknowledged that this method, as employed in this study, leads to overestimation of sulphate in highly coloured waters, particularly those with colour values in excess of 50 (which includes 73% of the study rivers) (Kerekes and Pollock 1983). Galloway (1985) has also recently reported a background level ($\sim$5.0 $\mu eq\ L^{-1}$) of sulphate in precipitation from remote precipitation monitoring stations indicating this level could be considered as a global background value.

Examining the spatial distribution of sulphate values, lowest values are reported for Ragged Harbour River (28 $\mu eq\ L^{-1}$) in the northeast corner of the island which is consistent with apparent regional depositional patterns. Highest values were reported for the Southwest River (Eastern Region) (65 $\mu eq\ L^{-1}$) while values in excess of 50 $\mu eq\ L^{-1}$ were reported for Northwest Brook, Gander River, Rocky River and the three sites on the Conne River. Low sulphate values were reported for rivers on the southwest coast, ranging from 31 to 38 $\mu eq\ L^{-1}$ (Dolland Brook to LaPoile River), which is somewhat surprising as this region is considered to likely have the highest rate of anthropogenic sulphate deposition.

Previous lake survey work has indicated a west to east gradient in sulphate levels, presumed in association with regional patterns in acid deposition (Scruton 1983). Total wet sulphate deposition as monitored by Environmental Protection Service (EPS) at Gros Morne National Park (western margin of province) was 15.4 kg ha^{-1} yr^{-1} (avg. SO_4^{2} conc. of 23.9 μeq L^{-1}) in 1981 and 19.9 kg ha^{-1} yr^{-1} (avg. SO_4^{2} conc of 27.9 μeq L^{-1}) in 1982. Similarly sulphate deposition, as measured at Terra Nova National Park (eastern margin of the province), was considerably less, ranging from 9.1 (1981) to 7.0 (1982) kg ha^{-1} yr^{-1} with average SO_4^{2} concentrations of from 17.3 (1981) to 17.9 μeq L^{-1} (1982) (Brian Power, Environment Canada, Environmental Protection Service, pers. comm.). Wet sulphate deposition on the Avalon Peninsula was also relatively high, ranging from 19.2 (1981) to 20.3 kg ha^{-1} yr^{-1} (1982) at Whitbourne and 21.1 kg ha^{-1} yr^{-1} at Cape Broyle in 1982 (Provincial Department of Environment, unpub. data). A precipitation monitor located at Bay D'Espoir on the south coast of the island reported SO_4^{2} deposition of 15.7 kg ha^{-1} yr^{-1} for 1982. It is apparent the west to east gradient in SO_4^{2} deposition may not hold true for the Avalon Peninsula. In addition, while the sulphate concentration in precipitation is relatively low, high annual precipitation for the island results in relatively high total annual sulphate loading. Sulphate deposition is approaching 20 kg ha^{-1} yr^{-1} which is acknowledged to be the level whereby sensitive aquatic systems can become seriously impacted by acidification (Bangay and Riordan 1983).

There has been no attempt to characterize or quantify dry deposition of sulphate or other pollutants in Newfoundland. It is generally acknowledged that dry deposition decreases as the distance from emmission sources (concentrations) increases. Dry deposition is estimated to account for 27% of all sulphate deposition in Eastern Canada and this proportion would be assumed to be smaller in Newfoundland on the eastern margin of North America (Summers et al. 1985). Aerosol deposition of sulphate in fog or in clouds (at high altitudes) must also be occurring and be unaccounted for in wet precipitation monitoring.

pH

The weighted mean annual pH of the 22 rivers (24 sites) varied from 5.08 to 6.27 (mean of 5.65) (Table 2). Twenty (20) of the study sites demonstrated a pH of less than 6.00, while no systems had an annual pH of less than 5.00 (Fig. 4). Rivers on the south coast of the island and the Northern Peninsula demonstrated the lowest annual pH's, 5.50 ($n = 11$) and 5.44 ($n = 2$), respectively. These regions can largely be characterized as containing rivers draining igneous bedrock (granites, gneisses), having rapid runoff and drainage, containing extensive rock and soil barrens within the watershed, with shallow acid soil cover and poor to no forest development; all characteristics of systems highly sensitive to acidification (Bangay and Riordan 1983).

Within these two broad geographical areas there are four rivers that do not fit the norm. The Northwest River (Northern Peninsula) has a considerably higher annual pH than its neighbouring river, the Cloud River (pH of 5.79 vs 5.08, respectively). This can be attributed to the presence of carbonate deposits within the Northwest River watershed (about 17% of the total area).

Similarly Pipers Hole, Conne, and LaPoile Rivers on the south coast have higher pH's than other south coast systems and this can be attributed to bedrock geology. The Conne River contains mafic volcanics in its watershed (~75%) while the LaPoile and Pipers Hole rivers have extensive sandstone, siltstone and conglomerate deposits in their watersheds (25% and 32% respectively). These geotypes are considered of intermediate sensitivity to acidification, and are considered to afford a greater ability to yield carbonates upon weathering than does the highly sensitive siliceous bedrock that dominates the drainage of the other rivers in these regions.

Rivers in the central part of the province had the highest mean annual pH's (6.19, n = 2), while the three Avalon Peninsula Rivers had a mean pH of 5.85. Central rivers largely drain geotypes of intermediate sensitivity to acidification (siltstones, sandstones, conglomerates, mafic volcanics) and are further characterized by extensive soil and forest development within the watersheds. Avalon rivers drain largely siliceous sedimentary bedrock with buffering potential afforded by cation exchange in clays, etc. Watersheds are characterized as small with high slopes and these systems respond rapidly to precipitation events. Avalon rivers are dominated by extensive soil barrens, scrub forest and organics. Eastern rivers also appear relatively acidic (mean pH of 5.71, n = 6) and these systems are characterized by considerable geological heterogeneity in their watersheds, extensive peatlands in the headwaters, and more moderate amounts of precipitation.

Alkalinity

Alkalinity values as determined by potentiometric titration and Gran plots and the routine two-end-point titrimetric method were correlated ($r = 0.65$, $n = 268$, $P \leq 0.001$), with no trend to the variability between measurements. Gran alkalinities are considered a more reliable and accurate measure in dilute waters (Stumm and Morgan 1981), and consequently were used to calculate bicarbonate ion and in all assessment of buffering status and acidification. The two-end-point method is considered to overestimate "true" alkalinity in waters sensitive to acidification (Henriksen 1982b). In addition, in low alkalinity waters, the presence of organics can also lead to a significant underestimation of alkalinity when the two-end-point acidimetric method is used (Driscoll 1980a).

The mean annual (weighted) alkalinities varied from 10 to 64 $\mu eq\ L^{-1}$ (mean of 27.2) (Table 2). These values, employing the Ontario Ministry of the Environment (1981) standards for acid sensitivity, would designate all study systems as highly to moderately sensitive to potential acidification ($<200\ \mu eq\ L^{-1}$ alkalinity). Twenty sites had alkalinities of $40\ \mu eq\ L^{-1}$ or less, indicating extreme sensitivity (Fig. 5). This is generally consistent with the lake inventory data base for the island (Scruton 1983; and unpublished data), where the majority of freshwater lakes (~90%) have been identified as of high to moderate sensitivity. The alkalinity of the study rivers is lower, in most instances, than for lakes sampled within their watersheds in the summers of 1981 (Scruton 1983) and 1983 (unpublished data). This may be in part due to the fact that alkalinity values for the rivers are weighted means which would reflect the range in alkalinity with respect to season, hydrology, etc., while

lake data is a single "point in time" sample taken during the expected period of maximum alkalinity (late summer). The distribution of alkalinity values confirms that rivers selected for study are highly susceptable to potential acidification.

Alkalinity in freshwaters is due primarily to the carbonate-bicarbonate-carbonic acid system, and all study systems were expected to have bicarbonate dominated buffer systems (Stumm and Morgan 1981). In dilute waters or acidifying waters (experiencing exhaustion of bicarbonate) other minor components of the buffering regime will assume increasing importance. Kramer (1976) states that waters with pH in the range of 4.0 to 6.0 may contain a number of additional buffer systems including conjugated bases of weak acids (silicic, phosphoric, hydrofloric, humic, fulvic), ammonia, hydrolyzable metals (aluminum, iron and others), or silica oxides. Aluminum and organic anions act as the most significant of these additional buffer systems in bicarbonate poor and/or acidifying waters (Henriksen and Seip 1980, Driscoll 1980b). The buffer intensity of these two components is at a maximum between pH 4.0 and 5.0, the end point of bicarbonate titration (Bisogni and Driscoll 1979).

Measured alkalinity in the study rivers has all been ascribed to bicarbonate ion. Dissolved organic carbon (DOC) and aluminum were only determined on a portion of samples collected and, owing to the difficulties in quantitatively determining the acid/base behaviour of dissolved organics and speciation of aluminum, the buffering potential of these two constituents has not been evaluated. Humics have been shown to have very low buffering capacity even when present in high concentrations (Wilson 1979). The buffering potential of aluminum is related to its concentration and the speciation of the metal, but generally the metal and its complexes are believed to be operative as a buffer only in the pH range 4.5-5.0 (Johannessen 1980). Organic complexing of aluminum will also diminish its buffering potential, and previous studies on Newfoundland's freshwaters have identified significant relationships between total aluminum and colour (or DOC), (Scruton 1983, 1984a) suggesting that much of the available ion is organically complexed.

It should be remembered that alkalinity provides a measure of sensitivity to potential acidification under current depositional regimes. It is, in effect, a measure of "residual" alkalinity, considering there has been consumption of bicarbonate alkalinity in response to loading of mineral and natural acids. Assuming that current calcium and magnesium levels (with assumed bicarbonate equivalence) best represent the acid neutralizing capacity of unstressed receiving waters and current alkalinity measures best represent residual alkalinity, the deficit in alkalinity can be determined. A plot of non-marine calcium and magnesium vs alkalinity indicates an appreciable alkalinity deficit on all rivers systems as equivalence is not achieved (Fig. 6). This relationship has been used to demonstrate consumption of alkalinity (bicarbonate) in response to loadings of mineral acids.

The alkalinity deficit for the 22 study rivers (24 sites) varies from 42 to 104 $\mu eq\ L^{-1}$ (mean of 68), and in most instances the deficit in alkalinity is greater than the residual (measured) alkalinity. By comparison lakes surveyed in insular Newfoundland in the late-summer and early-fall of 1981, an expected period of maximum alkalinity demonstrated alkalinity deficits in the range of

25-50 μeq L^{-1}. Both data sets provide an indication of the initial effects of acidification, that is an appreciable decline in alkalinity without total depletion of available buffering ability and resulting chronic depression of pH. In this type of situation episodic effects are possible and this will be considered in evaluating the temporal variability in alkalinity.

Organic Constituents

The organic content of the study rivers can be evaluated in relation to dissolved organic carbon (DOC) concentration (measured during the last three months of study only) and can be inferred from colour values (measured in all samples). Colour is a good indicator of dissolved organic content in freshwater (Hutchinson 1957) and the two parameters have been demonstrated to be interrelated in previous regional data sets (Scruton 1983, 1984a and unpub. data). Colour and DOC in this data set were also correlated ($r^2 = 0.56$, $P \leq 0.001$, $n = 69$). The mean colour of the study rivers varied from 31 to 91 T.C.U. (mean of 59). Using criteria developed for colour classification of lakes (Scruton 1983), six rivers would be characterized as brown water systems (colour of 30-50) while 16 rivers (18 sites) can be considered highly coloured (colour of > 50) (Fig. 7). Mean dissolved organic carbon (DOC) values (3 samples per river) varied from 3.0 to 11.3 mg L^{-1} (mean of 7.2).

The importance of dissolved organic constituents in the river chemistry is not surprising considering the large component of terrestrial organics associated with the river watersheds, ranging from 8 to 30% of the total watershed area (see Appendix 2, Table 2.2). The low relief in many headwaters (high level plateaus) coupled with poorly developed drainage patterns, high annual precipitation, cool temperature and low evapotranspiration rates have resulted in the formation of expansive areas of peatlands across much of the island, particularly in the northeast corner near Bonavista Bay. In addition low nutrient organic soils, particularly humic podzols and organic fibrosols and mesisols, dominate much of the drainage area of other biophysical types.

An important consideration is the contribution of organic acids as a major anionic component. Kerekes (1983) have suggested that organic acids ($COOH^-$) be included as an anion in coloured freshwaters and in computing ion balances. Oliver et al. (1983) have determined an organic acid equivalence of approximately 10 μeq of $COOH^-$ per mg of organic carbon (with modification by pH) in Nova Scotian waters. Single dissolved organic carbon values (determined for the last three months of the survey only) varied from 2.0 to 13.0 mg $L^{-1}C$ for the study rivers corresponding to 16 to 108 microequivalents of $COOH^-$ (Table 4). Assuming the above relationship for Nova Scotian lakes to hold true for Newfoundland's brown waters, the contribution of organic acids is considerable and in many instances greater than the other non-marine anions. Of a total of 69 samples with DOC analysis, 64 (93%) would demonstrate a dominance of organic acids relative to bicarbonate or non-marine sulphate. Organic acids were, however, not considered in the ion balance because: 1) the relationship between organic carbon and the equivalence of $COOH^-$ has not been determined for soft waters in Newfoundland, 2) dissolved organic carbon was not determined for all samples, making it impossible to compare DOC to

weighted mean values of other ions or to evaluate the seasonality of DOC availability, and 3) colourmetric determination of sulphate leads to overestimation in coloured waters which may be proportional to available organics.

Organic acids contribute to natural acidification of freshwaters (Henriksen and Seip 1980; Anonymous 1982), but because of the complex nature of the organic fraction it has been difficult to characterize or quantify this contribution. Component acids vary between regions and this influences the relative acidity of the organic fraction. Organics in freshwater, largely humic and fulvic acids, exhibit a fairly broad variability in acidic behaviour owing primarily to the range in dissociation constants (pK_A) of reactive groups, and the range in molecular weights from a few hundred to tens of thousands (Schnitzer and Khan 1972). However, the Oliver et al. (1983) method allows for quantitative approximation of organic anions which now can be routinely incorporated into evaluation of freshwater constituents.

It is apparent that the contribution of organics to the acid-base chemistry of dilute rivers in Newfoundland is considerable. Organics are an important contributor of hydrogen ions to freshwater and, a pH is an intensity function based on hydrogen ion concentration, organics will contribute to a decline in alkalinity and pH. Underwood and Josselyn (1980) have suggested a strong role for organics in alkalinity depletion and acidification in Nova Scotia lakes and have further gone on to state that anthropogenic acidification of lakes may not be a significant problem in Nova Scotia.

Jones et al. (1982) have demonstrated the influence of dissolved organic content on theoretical determinations of pH and alkalinity. For example, freshwaters with an alkalinity in the order of 30 $\mu eq\ L^{-1}$ (close to the average for the 22 rivers) would have a pH of 6.65 if no DOC was present but the pH would decline to 5.87 if 8 $mg\ L^{-1}$ DOC was present. Further, Kelso et al. (1986) in assessing data from 813 lakes in Eastern Canada, determined that lakes in Atlantic Canada had lower pHs for a given alkalinity than lakes in western localities for similar rates of mineral acid (sulphate) deposition, and that this broad regional difference could be related to the high organic content of Atlantic Region lakes (particularly in Nova Scotia and Newfoundland). However, not all the variability in pH-alkalinity relationships were attributable to organics.

The high organic content of insular Newfoundland's freshwaters poses three problems. Firstly, many of the empirical models developed to assess the regional effects of acidification (Henriksen's Nomograph, etc.) are strained in their applicability to brownwater systems. Secondly, highly coloured, soft waters are considered more vulnerable to acidification as atmospheric deposition of strong mineral acids will encourage dissociation of weaker organic acids (Henriksen and Seip 1980), resulting in more rapid depletion of bicarbonate alkalinity and pH decline. Thirdly, organics complex with available dissolved metals making it difficult to assess the coincident effect of acidification, that is the elevation of aluminum and other metals. Organics can act to diminish the toxic effects of aluminum by complexing the ion and limiting formation of the highly toxic labile aluminum species. Organics can

contribute to freshwater acidification and also complicate an assessment of the relative influence of anthropogenic pollutants.

Conductivity

Specific conductance or conductivity provides a measure of the total concentration of charged ions in a water sample and, as such, is considered to be a reliable indicator of sensitivity to acidification. Conductivity of the study rivers varied from 11.8 to 23.0 $\mu S\ cm^{-1}$ (mean of 16.7). Environment Canada (1981b) has considered freshwaters with a specific conductance less than 30 $\mu S\ cm^{-1}$ to be critically sensitive to acid precipitation, and this would include all of the study rivers. Comparatively, 86% of 109 lakes sampled in insular Newfoundland, and 97% of 130 Labrador lakes, had conductivities of 30 $\mu S\ cm^{-1}$ or less (Scruton 1983, 1984a).

Conductivities in insular Newfoundland (lakes and rivers) are higher than for Labrador's freshwaters, for systems of similar hardness, owing to the strong contribution of marine ions to freshwater chemistry and conductivity on the island (Scruton 1983, 1984a, 1984b). Conductivity is commonly related to the lithology of drainage basins, specifically to the solubility of minerals in the watershed, but in a region with strong marine influence, ions of marine origin (chloride and sodium) can obscure the influences of geochemistry. Marine ions account for an average of 53% of all ionic constituents in the study rivers and are obviously contributing a large component of the observed conductivity.

Conductivity is strongly related to certain ionic species (Ca^{+2}, Mg^{+2}, Cl^{-} for example) and less closely to others (HCO_3^-, NO_3^- for example) and is dependent upon the specific conductivities of each ion. Considering all 294 samples in the data set, conductivity was highly significantly correlated ($P \leq 0.001$) to the sum of anions ($r = 0.48$, $n = 293$), sum of cations ($r = 0.38$, $n = 294$), HCO_3^- ($r = 0.30$, $n = 294$), Na^+ ($r = 0.34$), Mg^{+2} ($r = 0.33$), Cl^- ($r = 0.31$), Ca^{+2} ($r = 0.25$) and with Al ($r = 0.47$, $n = 92$). Conductance, as a measure of ionic composition, is commonly associated with total dissolved solids, and in the absence of either measure the other can be calculated (McNeely et al. 1981). Conductivity and TDS for this data set were also highly significantly correlated ($r = 0.24$, $n = 294$, $P \leq 0.001$).

Bicarbonate to (excess) Sulphate Ratio

Oden (1976) and others have suggested that a comparison of the equivalence of bicarbonate and sulphate (or non-marine sulphate in regions exhibiting a strong marine influence) be used in a preliminary examination for acidification effects. Sensitive freshwaters influenced by atmospheric inputs of strong acid have lost much of their bicarbonate buffering capacity and sulphate, in the absence of significant inputs of chloride, becomes the dominant anion. Affected but non-acidified freshwaters characteristically are sulphate dominated with some residual bicarbonate while acidified freshwaters have exhausted their bicarbonate supply.

The bicarbonate to excess sulphate ratio (HCO_3^-: Ex SO_4^{2-}) for the 22 study rivers (24 sites) varies from 0.29 to 1.86 (mean of 0.75) and all but four systems demonstrated a sulphate dominance (Fig. 8). The three most mineralized rivers (Badger, Northwest, and Noel Paul's) and Colinet River demonstrated bicarbonate dominance. Rivers on the south coast of the island, with the lowest alkalinity values, not surprisingly demonstrated the lowest HCO_3^- to Ex SO_4^{2-} ratios ranging from 0.33 to 0.94 (mean of 0.60). The lowest ratio was 0.29 recorded for the Cloud River on the Northern Peninsula. The variance in HCO_3:Ex SO_4^{2-} was more attributable to the range in buffering ability ($[HCO_3^-]$ of 13 to 78 $\mu eq\ L^{-1}$) than the range in to atmospheric deposition (as indicated by [Ex. SO_4^{2-}] of 28 to 65 $\mu eq\ L^{-1}$). Comparatively, 49 of 94 dilute lakes (52%) in insular Newfoundland had HCO_3^-:Ex. SO_4^{2-} ratios of less than 1:00, and this was particularly true for lakes with a pH of less than 6.30 and with alkalinities of less than 40 $\mu eq\ L^{-1}$ (Scruton 1983).

Aluminum

Aluminum (Al) was measured in the study rivers initially in May 1981 (in some cases early June) and during the last three months of the study (March, April and May 1982) to determine the episodic availability of aluminum in the spring months, in relation to snowmelt and expected pH decline. All aluminum values are for total aluminum on unfiltered samples. Aluminum data is summarized in Table 5.

The ion is normally leached from upper soil horizons by carbonic acid and organic acid weathering (organic chelation) and is usually deposited in the lower soil horizons (Cronon and Schofield 1979). Under conditions of strong mineral acid deposition aluminum can be mobilized from the upper soil horizons and transported to receiving waters resulting in elevated values relative to "background" levels. This situation can be accentuated by episodes of high H^+ input and high discharge (rapid runoff). Aluminum is virtually non-existant in precipitation and the watershed is the primary source for the ion in freshwaters, being liberated from the catchment primarily through cation exchange (H^+ for Al).

Weighted mean total aluminum values (mean of 3 to 4 samples) ranged from 34 $\mu g\ L^{-1}$ (Conne River "C") to 177 $\mu g\ L^{-1}$ (Northwest Brook) with a mean of 57.3 (Table 2). Individual values ranged from 20 $\mu g\ L^{-1}$ (Pipers Hole River, April 1982) to 278 $\mu g\ L^{-1}$ (Northwest Brook, April 1982). For the most part, values were quite low with only 2 samples (2%) with an Al concentration of $\geq$200 $\mu g\ L^{-1}$ and additional 17 samples (18%) with Al concentrations from 100 to 200 $\mu g\ L^{-1}$. By comparison a survey of 109 headwater lakes in 1981 had aluminun values ranging from 0 to 430 $\mu g\ L^{-1}$ (mean of 112) with 12% of the values $\geq$ 200 $\mu g\ L^{-1}$ and 28% of the values from 100 to 200 $\mu g\ L^{-1}$. Aluminum values for two of the study rivers, as monitored by Environment Canada (from May 1980 to October 1984,) were found to vary from 20-190 $\mu g\ L^{-1}$ on Pipers Hole River ($n = 50$), and 20-190 $\mu g\ L^{-1}$ on Rocky River ($n = 47$). Some extremely high aluminum values were recorded (up to 1400 $\mu g\ L^{-1}$) but were always associated with extreme turbidity. Excluding these anomalies aluminum values exceeded 200 $\mu g\ L^{-1}$ only once (1 of 97 samples).

Driscoll (1980a) found organic complexes to be the dominant aluminum monomer in the highly acid Aridondack Region of New York State, and the concentration increased linearly with total organic carbon content. Johnson (1979) has reported that the presence of organic ligands can greatly enhance aluminum solubility by forming organic-aluminum complexes which are transported through the soil profile and into lakes and streams. There is a strong tendency for humics and fulvics to form complexes with metal ions, and these complexes can be the dominant species of the available metal (Stumm and Morgan 1981).

Aluminum in Nova Scotian rivers has been demonstrated to vary from 30 to 400 $\mu g\ L^{-1}$ (Clair and Komadina 1984), with 6 of 19 samples having values in excess of 200 $\mu g\ L^{-1}$. Aluminum values were highly correlated with dissolved organic carbon ($r = 0.87$). Aluminum levels in four Quebec north shore rivers varied from 16 to 236 $\mu g\ L^{-1}$ in 1981 (Brouard et al. 1982) and on the Escoumins River in 1982 from 20 to 340 $\mu g\ L^{-1}$ (mean of 156, $n = 34$) (Brouard et al. 1983), with 25% of the samples having values in excess of 200 $\mu g\ L^{-1}$. There was no clear relationship with water colour. Aluminum values from New England streams varied from 39 to 192 $\mu g\ L^{-1}$ and were positively correlated to organic anion concentrations (Haines and Akielaszek 1984).

Aluminum concentrations in this study were found to be significantly correlated ($r = 0.78$, $n = 92$, $P \leq 0.05$) (Fig. 9) with water colour (for dates Al was sampled) but poorly correlated to pH for same time period ($r = -0.13$, $n = 84$, $P = 0.28$). Previous lake survey data found aluminum concentrations to be correlated with both pH and water colour, but more significantly with colour (Scruton 1983, 1984a). Aluminum values as recorded during this survey are for total aluminum with no differentiation of the component species. The correlation with water colour would suggest much of available aluminum is present as organic complexes. A discussion on the speciation of aluminum in relation to toxicity to aquatic biota and seasonal aspects of aluminum availability are to follow.

Skartveit and Gjessing (1979) have also demonstrated variability in aluminum concentrations in relation to stream order. Higher Al levels were recorded in the headwaters (190-480 $\mu g\ L^{-1}$) than in the lower catchment (100-120 $\mu g\ L^{-1}$) in acidic Norwegian Rivers. Haines and Akielaszek (1984) also found higher aluminum values in headwater streams than in higher order streams in a study of New England salmon rivers. This is consistent with other observations on the high sensitivity of headwaters to acidification and can be explained by the lack of soil development and hydrologic characteristics of low order streams. Driscoll (1980a) compared aluminum speciation between lakes and streams in the Adirondacks and, although the difference was subtle, organic aluminum content was found to be higher in streams.

TEMPORAL VARIABILITY

Hydrology

The temporal pattern in hydrology of the study rivers and resulting influences on stream water chemistry can best be interpreted from eight of the

study rivers that are gauged by the Water Resources Branch of Environment Canada. These eight gauged rivers include Gander River, Ragged Harbour River, Gambo River (Middle Brook - the major tributary), Terra Nova River, Southwest Brook, Rocky River, Pipers Hole River and Baie du Nord River. One additional system, the Grey River, is also gauged by Water Resources Branch, but the hydrological record is incomplete during the study period (gauge was inoperative from mid-May to mid-October). The hydrological data for these systems, in particular the hydrograph for the study period, is presented along with temporal variation in key water quality parameters in Fig. 10-17. In addition, hydrological data for unstudied rivers (Environment Canada 1981a, 1982, 1983) is also examined for possible explainations of temporal variability in ungauged systems (data for St. Genevieve River as indicative of hydrological patterns for the Northern Peninsula rivers as an example).

The general hydrological pattern for most study rivers, from May 1981 to May 1982, is presented as follows. Peak discharge in the spring of 1981 occurred in early May followed by a recovery period (decline in discharge) through to early June. Early June through to mid-September was generally characterized by low flows, with several small peaks, or spates, in the summer months. Summer spates were more pronounced in the smaller watersheds (Rocky River, Southwest Brook for example, see Fig. 15 and 16). Discharge began to increase markedly in late September to reach an extreme peak in the third week of October. High flows continued through the late fall into the third week in December. Low flows generally characterized the winter months of January, February, and each March. Flows in association with snowmelt began to increase in mid-March with peak spring discharge in late April or May. Several smaller hydrological peaks were evident through the winter months (generally one in January, two in February, and a larger spate in mid to late March). For most study rivers summer low flows were less than winter low flows. Peak fall discharge was in the same order of magnitude as peak spring discharge.

The precise hydrological pattern and the timing of episodes varies from system to system but the above generalization is fairly representative of most of the study rivers. Hydrological data for St. Genevieve River suggests that peak snowmelt for Cloud River and Northwest Brook is delayed relative to other study rivers, with peak spring discharge in 1981 in the second week of May and peak spring discharges in 1982 in late May-early June. This is largely due to lower spring air temperatures in northern Newfoundland, and the fact that the headwaters for these rivers are located in the Long Range Mountains (elevation of approx. 550 m).

Comparisons of the hydrological data for the study period with historical stream flow summaries to 1979 (Environment Canada 1980) suggested that patterns evidenced from May 1981 to May 1982 were fairly representative of the period of record, with some exceptions. Highest fall discharge for most systems was recorded in the third week in October, while historical data records indicates that late November and early December is the usual peak flow period in the fall months. Unusually high precipitation in late September-early October is the cause of this early peak (Environment Canada 1981c). Precipitation monitoring stations on the island recorded measurable precipitation on 16-21 days with a total monthly rainfall of 520-680 mm in October 1981. Historical hydrological data for Isle aux Morts River and Grey River suggests that the month of peak

discharge for rivers on the southwest coast is frequently May (usually the first 2 weeks), while in 1982 peak spring discharge was evident earlier, in late April on south coast systems. August and September are usually the low flow months for the summer period but 5 of the 8 gauged systems had June 1981 as the low flow summer month during the study period, likely due to pronounced spates in both July and August.

There is also evidence in the hydrological record to suggest that the magnitude of the snowmelt effect in insular Newfoundland is not as great as it is on mainland rivers, particularly in Central Canada. Large parts of insular Newfoundland demonstrate that November and December, and often through to March are the wettest months of the year, while the following spring months are often the driest (MacPherson and MacPherson 1982). On many parts of the island, particularly the south coast and Avalon Peninsula, there is minimal snowpack cover and snow accumulation is discontinuous through time and variable in depth. Mild winter storms from southern latitudes frequently cause several significant runoff periods through the winter, not allowing snowpack (and pollutant load) accumulation. As a result the major snowmelt in the spring is often reduced in magnitude, and the pollutant load is presumably similarly reduced.

River hydrology, as measured by discharge, is a major controlling feature of river water chemistry and is related to assorted other hydraulic factors within the watershed. Variations in the chemical composition of waters can, in part, be explained by the mixing of waters (runoff, groundwater, etc.) with ranging residence times in soils, etc. and therefore different chemical composition (Harvey et al. 1981). In areas of similar geological composition, short residence time waters will be more dilute (Potter et al. 1982) and have lower pH than waters of longer residence time. In addition, rivers with considerable peatland in their watershed have great storage potential, but retention in organic deposits may contribute to natural acidification of surface waters.

Rivers on the south coast of the island have many hydraulic characteristics which contribute to their sensitivity, including high amounts of rainfall and runoff, extensive rock and soil barrens, and virtually non-existent soil cover. In this type of terrain there is limited opportunity for rainwater to infiltrate the shallow soil cover (which is characterized as of low pH and high in organic content in any event), interact with vegetation, or enter into the subsurface (ground) water. Many river systems on the southwest corner of the province are characterized by extremely high slopes (elevation in relation to distance from headwaters to river mouth) and high annual precipitation (~2000 mm per year). Standing water in these watersheds is estimated to be in the order of 10 to 15% by area and is associated primarily with numerous small, shallow lakes. Some south coast rivers (Grey River, White Bear River, for example) may be more sensitive than they were previously, due to the diversion of much of the standing waters in their upper watersheds for hydroelectric generation. Conversely some of the less sensitive watersheds (Gander River, Badger River, Noel Paul's Brook) are typified by moderate gradient, lower rainfall and runoff, good soil and forest development in their watershed and more standing water storage potential (larger, deeper lakes).

The ability to evaluate in detail the variability in stream chemistry with time is difficult owing the many different processes involved and the seasonal variability in the involvement of these various processes. While the linkages of chemical variability with river hydrology can be determined, it is not possible to qualify the mix of water sources from a hydrograph alone. Water storage within a watershed will play a large role in determining the magnitude of influence snowmelt will have on stream chemistry and the timing of this effect. Watersheds with large storage potential will demonstrate a lag in effect, as the "slug" of acid meltwater is delayed and ameliorated. For example, studies on calibrated watersheds in Canada have determined that the response time of watersheds to snowmelt can vary from 0.5 day (Lac LaFlame, Quebec) to 4 days (Mersey River, Nova Scotia) (Marmorek et al. 1984).

In order to evaluate the representativeness of data collected over the study period to historical data a comparison of hydrological data for the gauged study rivers over the study period with long term average data is made (see Table 6). It is initially apparent that runoff over the study period is appreciably higher than normal ranging from 6% (Rocky River) to 45% (Pipers Hole River) higher than the long term average. A further examination reveals 1981 was an extremely high flow year and, in the case of Baie du Nord River, the highest runoff year over the 31 year period of hydrological record. On a monthly basis, runoff in the fall months of 1981 was much higher than usual, and this situation was extreme in October. For 7 of the 8 gauged study rivers flows in October were higher than any on record, ranging from 4% (Terra Nova River) to 63% (Baie du Nord River) greater than the previously recorded highs for that month. Flows in June 1981 on Pipers Hole River and in July 1981 on Rocky River were also the highest monthly runoff on record for these systems. This higher than usual annual runoff will result in a greater dilution of base flows and greater contribution of precipitation chemistry to river chemistry, than in other years. The seasonal dynamics of the runoff pattern will also result in water chemistry recorded during high flow periods greatly influencing the calculation of weighted mean data.

Barnes (1984) has studied the hydrological characteristics of small peatland dominated catchments on the Avalon Peninsula. Previous literature (Romanov 1953, and others) had suggested peatlands play a role in moderating runoff by soaking up water during precipitation events and releasing water during droughts. Barnes' studies suggests that peatlands in Newfoundland are frequently near saturation and response to precipitation events is rapid due to limited absorption capacity. Under normal wet conditions experienced in peatlands organic deposits do not act to moderate runoff. This is apparent in the hydrograph of some of the smaller watersheds with considerable peatlands in the headwaters (Ragged Harbour River, Southwest Brook, Rocky River) where spates are frequent and often extreme.

pH

Their is considerable seasonal variability in pH for the study rivers over the 13 month study period and the minima, maxima and volume weighted means (for 13 month period of study) are contained in Table 7 and Fig. 18). The difference between minimum and maximum values (or range) in pH varied from a

low of 0.96 to a pH unit (Gander River, Badger River) to a high of 2.28 units (Biscay Bay Back Brook).

Three systems (Gander, Badger and Noel Paul's) demonstrated an annual range in pH of less than 1.0 unit. These rivers, in the central region, are characterized by extensive soils and forest development and are underlain by geotypes of moderate sensitivity to acidification. The pH minima and weighted means for these rivers were also relatively high (minima of 5.75, 5.82, 5.99, and means of 6.07, 6.11, 6.27, respectively) suggesting considerable inherent buffering capacity within the watersheds. Considering the titration curve for bicarbonate buffered aquatic systems with strong acid (Stumm and Morgan 1981), this relatively narrow range in pH suggests the presence of intact buffering regimes, where appreciable H^+ neutralization is possible without coincident declines in pH.

Eight river systems demonstrated a range in pH from 1.0 to 1.5 units, while eleven other rivers demonstrated a range from 1.5 to 2.0 units. Most of the highly sensitive south coast and eastern rivers demonstrated these wide amplitudes in pH. The wide pH range for these sensitive rivers is also consistent with the dynamics of bicarbonate titration. In these low alkalinity rivers, H^+ inputs are acting on the lower end of the titration curve where sharp declines in association with depletion of alkalinity are possible.

Two rivers had an amplitude in pH of greater than 2.0 units; Indian Bay River (2.04 units) and Biscay Bay Back Brook (2.28 unit). The wide range in pH for Indian Bay River is not surprising owing to the sensitivity of much of the bedrock in the watershed and the large component of organics in the headwaters (42%). The pH minima (4.66 in October 1981) is a marked excursion from the annual cycle, but a similar trend in alkalinity is also apparent. The high runoff experienced in October caused an appreciable decline in pH that may be primarily attributable to an influx of organic acids. Biscay Bay (Back) Brook is the smallest watershed (28 km^2) included in the survey and dominated by barrens and scrub forest and therefore highly susceptible to episodic influences. Water quality samples collected from May 1984 to July 1985 ($n = 9$) on Biscay Bay River have recorded pH's ranging from 5.36 to 6.12, $\bar{x} = 5.64$) (W. G. Whelan, Department of Fisheries and Oceans, Fisheries Research Branch, P. O. Box 5667, St. John's, pers. comm.). It is apparent the Biscay Bay system is very acidic and the extreme low pH recorded in October 1982 is possible considering runoff conditions for that month.

The wide flux in pH over the study period was considerable and warrants some additional examination. For seven of the gauged study systems, there is available historical water quality data, as collected by Environment Canada, at monthly intervals or less frequently. A comparison of historical pH data with data collected in this survey is contained in Table 8. The historical pH data for several of the gauged study rivers (1972 through 1984) suggests that the pH ranges and minima recorded in May 1981 through May 1982 are characteristic of these soft water systems. For example, for the Terra Nova River, the mean pH for 9 years of record (1970-79; $n = 109$) was 5.88 as compared to 5.64 (this study), while the annual flux varied from 1.0 to 2.0 units (average of 1.44) over the 9 years as compared to 1.55 (this study). For several rivers mean pH recorded in 1981-82 is near the low range end of the range for the period of

record; in some cases (Pipers Hole, Rocky Rivers) lower than previously recorded annual means. This suggests atypical acid inputs during 1981-82, possibly due to biases created by sampling schedule or alternatively progressing acidification of these systems. Additionally the high runoff experienced during the study period will contribute to lower pH's relative to other years or long term averages.

The acidity of precipitation, as recorded at a variety of monitoring sites across the island, was examined to see if a wide variance in precipitation pH could be related to variability in river pH. Precipitation pH (sampled weekly or less frequently) at Gros Morne National Park on the west coast varied from 4.25 to 5.70 (a difference of 1.45 units) in 1981, and from 4.00 to 6.05 (2.05 units) in 1982 while at Terra Nova National Park, precipitation acidity varied from 4.10 to 5.55 (1.45 units) in 1981 and from 4.10 to 6.05 (1.95 units) in 1982 (Environmental Protection Service, unpubl. data). Precipitation pH recorded at Avalon Peninsula monitoring sites varied from 3.88 to 6.39 (2.51 units) in 1981 (May to December), and from 4.43 to 5.66 (1.23 unit) in 1982 at Whitbourne, while at Cape Broyle precipitation acidity varied from 4.20 to 4.90 (0.70 unit) in 1981 (August to December) (Newfoundland Department of the Environment, unpubl. data). There is certainly wide variance in the acidity of precipitation and certainly the variance would be even greater if the acidity of individual precipitation events was considered. Being on the eastern extreme of the zone of influence of major pollution concentrations in Eastern North America also contributes to the variance on precipitation acidity. Weather patterns may originate over high emissions areas or conversely they may originate over more northern latitudes with minimal acid causing emissions. Additionally, being thousands of kilometers downwind of emission concentrations, much of the pollutant load is being scavenged by precipitation prior to reaching insular Newfoundland.

Examining the trends in precipitation acidity of the EPS precipitation monitoring site in Terra Nova National Park there is evidence of seasonal variability in acid deposition over the study period (unpub. data). Precipitation acidity (2 week composite samples) demonstrated a pH of less than 5.0 for the summer months of 1981 (May through early September) and again in the spring of 1982 (late March through the end of May). Winter precipitation, the bulk as snow, demonstrated a pH of greater than 5.0 from mid December through to late March. Similarly sulphate concentrations are highest in the summer months of 1981 and again in the spring of 1982. Fall samples demonstrated a marked (4 fold) increase in entrainment of marine ions as compared to summer values. It is possible the ion exchange phenomenon demonstrated by Norwegian researchers (Seip and Tollan 1982), largely Na^+ for H^+, may possibly contribute to fall pH depressions on some river systems.

The monthly variation in pH was correlated ($P \leq 0.25$) (negatively) to discharge on 20 of the study rivers (significantly, $P \leq 0.05$, on 13 systems) (Table 9). Many authors have demonstrated an inverse relationship between river discharge and pH and, in soft water systems experiencing considerable acid deposition, this situation can be enhanced. In most of the study rivers two periods of pH depression are evident, both in association with peaks in the hydrological cycle when precipitation and/or meltwater is a major contributor to water chemistry (see Fig. 10-17). Highest pH's were observed during the low

flow summer period, where base flow is the major contributor to runoff, and in mid winter, when flows are reduced due to precipitation accumulation in the form of snow.

The situation can simply be described as a dilution of base flow (groundwater) with runoff during peaks in the hydrological cycle. Runoff is more acidic than base flow due to limited interaction with available acid neutralizing agents in the terrestrial confines of the watershed. During high flow periods only surface reactions (ion exchanges) can operate to modify incoming precipitation and reduce runoff acidity. Storm events will also flush peatlands of organic and biogenic sulphuric acids leading to variability in the contribution of natural acids in relation to hydrology. Snowmelt releases accumulated pollutants from the snowpack and the magnitude of the input and the partially frozen nature of soils reduces the watersheds ability to reduce runoff acidity.

The magnitude of pH depressions (acid shock) from snowmelt will depend upon the quantity and quality of precipitation and meltwater and the degree to which runoff is exposed to interactions with the watershed. Slight pH depressions were noticeable even in the moderately well buffered watersheds (Gander River, Noel Paul's Brook, Badger River). As snowmelt proceeds rapidly, and often over frozen overburden, limited acid neutralization is possible even in watersheds with appreciable bicarbonate reservoirs. pH minima on these systems are still relatively high suggesting adequate interaction to reduce the magnitude of any acid pulse.

An important consideration in assessing the episodic excursions in pH for each system is the timing of the minimum pH. For the most part, study rivers divide into two groups; those that experience pH minima in the late fall, in association with heavy fall rains, and those that experience minima in the spring in association with snowmelt and runoff. Nine rivers had fall minima (September, October, November, and December 1981) while thirteen rivers had spring pH minima (March and April 1982). April 1982 was the month with most rivers (12) experiencing minima pH, suggesting a strong snowmelt effect in 1982. The majority of the south coast rivers (10 of 11) experienced pH minima in spring (April) while the timing of pH minima was variable in other geographical regions. The difference in timing of the pH minimum also has varying implications for aquatic biota, (to be discussed later). All rivers experience pH excursions in both the fall and spring and the evidence of pH minima in either season may be determined by the sampling schedule in relation to discharge. It follows that the timing and magnitude of pH depression (from year to year) will be determined by climatological patterns and spatial and temporal variability in deposition and accumulation of acids.

The occurrence of fall pH minima on insular Newfoundland rivers is not surprising owing to the importance of natural (organic) sources of acidity, seasonality of sulphate storage and H^+ neutralization, high rainfall experienced in the late fall months (MacPherson and MacPherson 1982), and climatic influences on the acidity of snowfall and snowpack accumulation. Sorenson in Christophersen et al. (1984a) argue that autumn floods can produce fluxes in H^+ and other ions in the same order of magnitude as spring floods. Corbett and Lynch (1982) observed a decline in stream pH of 2.37 units (7.32 to

4.95) in 36 hours in response to a large acidic rainfall in October in a North Carolina stream.

pH minima ranged from 4.62 (Baie D'Espoir River-April 1982) to 5.99 (Noel Paul's Brook-November 1981). Nine rivers demonstrated pH minima less than 5.00, with an additional seven rivers with pH minima from 5.00 to 5.25 (see Fig. 18). Minimum pH followed similar trends in other assessment of pH and acid sensitivity with the more mineralized systems demonstrating highest pH minima and the sensitive south coast and eastern rivers the lowest minima. Excursions to pH 5.25 and less and the amplitude in pH values over the 13 month study period points to the extreme sensitivity of many insular Newfoundland rivers and provides evidence of transient episodic acidification. Many study rivers are demonstrating pH levels that are potentially threatening to aquatic biota.

The monthly sampling schedule unfortunately did not permit evaluation of these episodes in greater detail. On many rivers, particularly on the south coast, the April 1982 sample was collected at, or near, maximum spring discharge and the pH recorded may be representative of the extreme low for the period of snowmelt. On other systems (Eastern rivers for example), the April 1982 sample was collected 5-7 days prior to maximum discharge and further declines in pH may occur on these systems at peak discharge (maximum dilution). Studies in Scandinavia have found that, while there is a major outwash of impurities in the early phase of snowmelt (50-80% pollutants released in the first 30% of meltwater) the high levels of H^+ can last considerably longer than the early peak in sulphate concentrations. Researchers in Ontario (Jeffries and Semkin 1983, Jeffries and Synder 1981) have found temporal patterns in stream chemistry during snowmelt to be different from those observed in Norway (Johannessen et al. 1980). They found maximum H^+ concentrations (lowest pH) to occur after peak stream discharge. More frequent sampling (weekly, daily) would be required to determine the magnitude and duration of pH depressions in Newfoundland to precisely define the exposure limits of low pH to aquatic biota.

Maximum pH varied from 5.84 (Cloud River-July 1981) to 7.21 (Ragged Harbour River-September 1981). Two Avalon Peninsula rivers, Biscay Bay (Back) Brook and Colinet River, also demonstrated maximum pH in excess of 7.00 (7.06 for both). Most rivers demonstrated pH maximum in the spring of 1981, 11 of those rivers in May 1981 and 8 in July 1981. The May 1981 sample was collected at the end of the decline in discharge after the peak snowmelt of the spring of 1981 near the low flow point for that month. The hydrograph for many of the gauged systems suggest no major precipitation events for 3 weeks prior to collection of the May 1981 sample. The July sample was also collected 7-10 days after a major spate and the preceeding month (June) was the low flow month for the summer period for many rivers (Environment Canada 1982).

Thompson et al. (1980) has demonstrated considerable variability in annual pH in some soft water Newfoundland rivers through the 1970's and suggests that this year to year variance can in part be attributed to changes in anthropogenic inputs. For example the annual pH for Isle aux Morts River ranged from 4.7 (1973) to 5.9 (1976) during the period 1971-76 while Rocky River demonstrated a range from 5.15 (1972) to 6.25 (1975) over a similar time

frame. It is apparent that soft water rivers in insular Newfoundland demonstrate extreme variability in acidity even when measured on an annual basis (mean values determined from 12 single samples). This makes it difficult to categorize rivers as to acidity and susceptability to acidification on the basis of one sample or one year of sampling. This wide variation in annual pH is, in itself, a measure of the sensitivity of these rivers to acid deposition and the limited neutralizing capacity to buffer pulses of high runoff. The fact that the pH of these systems recovers in low depositions years also indicates some residual buffering capacity within the watersheds, and that these rivers are not chronically affected.

Alkalinity

Alkalinity (field measured values) was also correlated ($P \leq 0.25$) to discharge on all but three of the rivers (excluding Gander River, Terra Nova River and Biscay Bay (Back) Brook) and was significantly correlated ($P \leq 0.05$) on 12 of the systems (Table 9). Figures 10-17 demonstrate that the seasonal trends in alkalinity follow very closely those of pH. The factors interacting to cause the seasonal variation in alkalinity are essentially the same as for pH and will not be dealt with in detail.

It is important to note many researchers have found alkalinity to increase substantially as one moves downstream and this is mostly attributed to increased soil contact time and glacial removal of overburden (Marmorek et al. 1984). Our samples, taken near the river mouths, reflect an average condition for all the lotic habitat in the river and may reflect optimum conditions for the system. The extent and magnitude of alkalinity declines is undoubtedly magnified as you approach the headwaters of the respective systems.

Alkalinity minima occurred at different times of the year and April 1982 was again the month in which most alkalinity mimima occurred (10 rivers). A number of rivers had minima in December 1981 (5 systems including all 3 sites on the Conne River). It is interesting to note that while seasonal trends in pH and alkalinity were closely linked, the occurrence of the pH minimum did not always coincide with the minimum alkalinity, and the two minima occurred in the same month on 10 rivers only. The lowest alkalinity occurred on Southwest Brook (-18 $\mu eq\ L^{-1}$ in December 1981) and negative alkalinities were recorded on this system in April 1982 as well. Total depletion of alkalinity (0 or negative) was evident on Terra Nova River, a neighbouring system, in three months (December 1981, January 1982, April 1982) and Biscay Bay (Back) Brook for January and February of 1982. Hydrographic data on nearby Rocky River suggests it is unlikely this situation persisted over that time span. Negative alkalinities were experienced in the month of April on eight systems, supporting other evidence of a significant snowmelt effect in the spring of 1982. Nine systems demonstrated alkalinity minima in the 0-20 $\mu eq\ L^{-1}$ range with 5 rivers having alkalinity minima between 20 and 40 $\mu eq\ L^{-1}$. Again the more mineralized rivers in central Newfoundland (Gander River, Noel Paul's Brook, Badger River) and Northwest Brook, with calcareous deposits in the watershed, demonstrated the highest minimum alkalinities.

Cations

Calcium concentrations were inversely correlated ($P \leq 0.25$) to discharge on 14 rivers (significantly on 5 rivers, $P \leq 0.05$) (Table 9). The variation in calcium levels in most watersheds generally followed the reverse of the hydrograph (Fig. 10-17). Highest calcium concentrations were recorded in the summer and mid-winter with lowest levels generally occurring during the high runoff periods (October-December 1981), followed by a noticeable decline in April 1982. Highest values for many river systems, particularly on the south coast, were experienced in February 1982; the low flow month in mid-winter. In low flow periods, groundwater (base flow) contributes proportionately more to river chemistry then does runoff with ground water tending to be more mineralized than surface runoff, owing to increased contact time with bedrock and overburden (Wright and Johannessen 1980). This is particularly true in mid-winter when precipitation accumulates in the snowpack and surface runoff is minimal. Most ions of terrestrial origin (Ca^{+2}, Mg^{+2}, HCO_3^-) then experience significant dilution during hydrological episodes.

Magnesium concentrations were inversely correlated ($P \leq 0.25$) with discharge on 15 rivers (significantly on 4 rivers, $P \leq 0.05$) and the seasonal dynamics of magnesium availability followed very closely that of calcium (Table 9, Fig. 10-17). Ragged Harbour River, the only system that demonstrated non-marine magnesium dominance over non-marine calcium, had the highest magnesium value recorded in August 1981 (117 $\mu eq\ L^{-1}$). Ragged Harbour River and some central rivers had highest cation concentrations ($Ca^{+2} + Mg^{+2}$) in late summer and early fall. The hydrograph for Ragged Harbour River points to late summer (August 1981) low flows being appreciably less than mid-winter low flows (February 1982), suggesting considerable base flow (groundwater) contribution in that month.

Johannessen et al. (1980) has suggested that snowmelt can be characterized as three phased. Initially there is an increase in Ca^{+2}, Mg^{+2} and HCO_3^- through a release of entrapped groundwater. In the second phase, there is an increase in anions of precipitation origin, mostly Cl^- and SO_4^{-2}, due to ion separation and leaching from the snowpack. This is followed by a large dilution effect when most of the snowpack is melted and discharge is approaching maximum for the event (Johannessen and Henriksen 1978). The concentration or fractionation effect observed by Johnannessen has also recently been observed at a number of Canadian locations including Turkey Lakes (Jeffries and Semkin 1983) and Dorset (Scheider et al. 1984) in Ontario and Lac LaFlamme (Jones et al. 1984) in Quebec. Sampling in April 1982 during the major snowmelt for many river systems indicated low cation levels, particularly in relation to February 1982 peak levels. Samples were taken at or near the peak in discharge for the snowmelt event for many of the study rivers (particularly the south coast). It is likely the initial elevation of minerals in association with entrapped groundwater occurred days or weeks prior to sampling, and April 1982 samples reflected a strong dilution effect.

Sodium was negatively correlated ($P \leq 0.25$) to discharge on 14 study systems (significantly on 4 rivers, $P \leq 0.05$) with non-marine sodium correlated to discharge on 13 rivers (Table 9, Fig. 10-17). The seasonal dynamics in sodium concentrations are somewhat harder to interpret owing to the varying

sources for the ion, with both major terrestrial and precipitation inputs (previous evaluation suggests 64% marine contribution on the average). Input-output budgets for Norwegian catchments suggest that Na^+ is weakly bound in soil and moves fairly easily through the catchment (Overrein et al. 1980). For the south coast rivers, temporal variability in sodium followed closely that of the other base cations. An additional confounding problem in interpretation is the possibility of cation exchange, primarily marine sodium for calcium, as previously demonstrated for the Isle aux Morts River on the south coast of Newfoundland and for Northeast Pond River on the Avalon Peninsula (Thompson 1982a, 1983). Thompson states that this phenomenon may also occur on many other soft water, coastal rivers in Atlantic Canada. However, in this study only 2 of 294 samples demonstrated negative values for non-marine sodium and, in both cases, there was no coincident elevation of calcium suggesting no evidence of large scale ion exchange of marine sodium for calcium.

Seip and Tollan (1983) investigated short term (seasonal and episodic) acidification of runoff in Norwegian rivers also due to ion exchange reactions involving sea salts, largely marine sodium for H^+. They concluded that this process was of minor importance relative to the large anthropogenic input of H^+ ions in southern Norway and ion exchange for sodium does not contribute to long term acidification. In our region, anthropogenic inputs of H^+ are not as great as southern Norway. There is, however, very high deposition of marine sodium and this type of ion exchange reaction may be a significant contributor to short term pH depressions. Overrein et al. (1980) suggest that cation exchange involving marine sodium and H^+ may contribute significantly to seasonal pH variations in areas with large deposition of sea salts.

Potassium was negatively correlated ($P \leq 0.25$) to discharge on 13 systems (significant on one river, $P \leq 0.05$) and demonstrated similar seasonal patterns to the base cations, calcium and magnesium (Table 9).

It should be remembered that, although cation concentrations are diluted during high runoff periods, peak flows may contribute a high proportion of the total annual cation export. Thompson (1982a) suggested, using the Isle aux Morts River as an example, that a fall peak in cation levels, coincident with peak discharge, indicates that the major annual contribution of cation export may be in association with heavy fall rains.

Sulphate

Sulphate was positively correlated ($P \leq 0.25$) to discharge on 8 systems (significantly on 2 rivers, $P \leq 0.05$), while non-marine sulphate was positively correlated ($P \leq 0.25$) to discharge on 6 systems (highly significantly on 1 river, $P \leq 0.05$) (Table 9), reflecting the importance of surface runoff and precipitation as a major source for this ion. Sulphate was, however, not correlated to discharge for any of the south coast rivers (with the exception of Long Harbour River). For most study systems sulphate values, were relatively high throughout the summer of 1981, with peaks in the fall from September through December (most frequently in September) while low sulphate values were characteristic of mid-winter months (Fig. 8-15).

When evaluating the temporal variations in SO_4^{2} levels in study rivers it is important to consider that internal cycling of sulphate can be comparable to the magnitude of the input/output flux (Cristophensen and Wright 1981; Seip et al. 1985). Studies in Scandinavia have confirmed that SO_4^{2} does move rather freely through an aquatic system (Skartveit 1981) and on a long-term basis (1 year or more) input/output budgets are generally constant. However, there is a marked seasonal flux in sulphate movement through the watershed which is interlinked with the hydrological cycle (Skartveit and Gjessing 1979). Sulphate generally accumulates during low flow periods, largely through vegetational uptake during the period of plant growth and moderate precipitation in the summer, and through accumulation in the snowpack in the cold winter months (Dovland and Semb 1978). There is usually a net loss in SO_4^{2} (output is greater than input) as a result of washout during high flow periods (fall, spring) (Cristophersen and Wright 1981; Christophersen et al. 1984b). Galloway et al. (1980) also found SO_4^{2} concentration to increase from snowpack to receiving waters during snowmelt suspecting an outwash of terrestrially stored sulphate during snowmelt as well. A significant sulphur input can also occur in heavy rainfall periods due to saturation of organic soils where biogenic sulphur reservoirs exist.

It is also important to consider there is wide amplitude in anthropogenic inputs of sulphate in precipitation and thus will affect the sulphate levels observed in the runoff and receiving waters. For example precipitation samples collected (weekly) at Terra Nova National Park in 1981 demonstrated non-marine sulphate variation from 3 to 69 $\mu eq\ L^{-1}$, a 23 fold increase (Environmental Protection Service, unpub. data). At Whitbourne on the Avalon Peninsula the variation in non-marine sulphate in precipitation was even more extreme, from 7 to 116 $\mu eq\ L^{-1}$ for 1981, also a 23-fold increase (Newfoundland Department of the Environment, unpubl. data). Unfortunately the spatial and temporal pattern of sulphate deposition on the island is not well enough defined to permit a rigorous comparison with observed variations in water chemistry.

In several river systems there is a small sulphate peak in April 1982, relative to mid-winter values, and this is particularly evident on central and east coast rivers. The hydrographs for Terra Nova River, Gambo River and Gander River indicate the April sample was taken on these systems several days prior to peak discharge (which occurred May 2-4). South coast rivers did not demonstrate noticeable increase in SO_4^{2} in April 1982, and rivers west of Baie D'Espoir demonstrated a slight decline from March 1982 values. The hydrograph for Pipers Hole River and hydrological data for unstudied south coast rivers (Isle aux Morts River and Grandy Brook; Environment Canada 1982) indicates the April 1982 sample was taken very near (within one day) the peak discharge for the main snowmelt event that spring. Runoff on the two Northern Peninsula Rivers (Cloud River, Northwest Brook) was delayed relative to the rest of the study rivers with peak discharge in late May (26-27) with an elongated peak to June 7 (Environment Canada 1983; data for St. Genevieve River). There is evidence of a slight increase in SO_4^{2} values in May 1982 for these two rivers.

This situation with respect to temporal variability in sulphate, and sampling schedules in relation to peak snowmelt for 1982, appear to be consistent with the Johannessen et al. (1980) concept of a three phased snowmelt. Initially, in snowmelt, there is rise in ions or terrestrial origin

(Ca^{+2}, Mg^{+2} and HCO_3^-) followed by a second phase characterized by elevation of anions from the snowpack, mostly Cl^- and SO_4^{-2}, due to ion separation and leaching (fractionation effect). It is possible central and east coast rivers, sampled several days (5-7) prior to peak discharge, demonstrated SO_4^{-2} peaks in April due to this second phase of snowmelt. The third phase in snowmelt corresponds to dilution of all ions at maximum discharge, as the snowpack loses much of its inpurities in the initial melt waters, and this appears to be the situation for SO_4^{-2} levels on south coast rivers in April. More frequent sampling would be required to confirm the variability in sulphate levels in relation to the timing of spring snowmelt on Newfoundland Rivers.

The peak in excess sulphate values in the fall corresponds to a similar peak in colour values for many of the study rivers (11 systems) and this peak is most evident in September (15 rivers) (see also Fig. 10-17). Excess sulphate and colour were highly correlated for the entire data set ($r = 0.46$, $P \leq 0.001$, $n = 294$). This suggests sulphate may be being stored or assimilated (as H_2S or $(CH_3)_2S$) in peatlands during the period of plant growth in the summer. In the fall, with ceasation of growth, bacterical degradation, and flushing of these organic reservoirs, sulphate is being released along with dissolved and particulate organics Kerekes et al. (1982). In Nova Scotian lakes, Kerekes et al. (1982) have indicated that organic deposits can act as sulphur reservoirs (sulphate is reduced) and sulphate can subsequently be produced by bacterial oxidation and transported to receiving waters during major hydrologic events. Machell et al. (1985) has suggested that sulphuric acid of natural origin (from peats and bogs) is present in Nova Scotian lakes as evidenced by stong correlations between sulphate and total organic carbon. Likens et al. (1976) have demonstrated sulphate accumulation during the summer followed by later release in Hubbard Brook in New Hampshire. Ogden (1982) has also presented evidence for H^+ and SO_4^{-2} accumulation in watershed during summer months in small Nova Scotian watersheds and, in bog dominated catchments, he suggests the principle mechanism is reduction to H_2S. It is also possible that colourimetric interference in sulphate determination (by the MTB method) may be "enhancing" this apparent relationship.

Dovland and Semb (1978) found that the seasonal pattern and magnitude in sulphate variability seemed to be primarily controlled by the flux in water. In one catchment they studied, one half of the annual SO_4^{-2} output from the watershed occurred over a 2 week period in the fall due to heavy rains. They also observed a wide seasonal variation in sulphate storage within watersheds and attributed this variability to vegetation uptake and soil accumulation during dry summer months.

Chloride

Chloride was negatively correlated ($P \leq 0.25$) with discharge on 9 rivers (significant on 2 rivers, $P \leq 0.05$) (Table 9, Fig. 10-17). The seasonal pattern in chloride levels for the study systems is fairy consistent from river to river. Relatively constant levels of chloride are typical for the first seven to eight months of study, largely to December 1981. Most systems then demonstrated some elevation of chloride through the winter months and this is most noticeable on south coast and Avalon Peninsula River systems.

This may in part be due to seasonal modifications of weather patterns although winter air circulation usually features a mean vector wind from the west (MacPherson and MacPherson 1982). However, southern Newfoundland and the Avalon Peninsula are often affected by mild winter storms from southwest and southerly air circulation resulting in frequent mid winter thaws and small snowmelts. Chloride and sulphate are frequently elevated in early stages of snowmelt due to ion separation and leaching, and this phenomenon may have contributed to the elevation of this ion during winter months prior to the major snowmelt event. The very appreciable elevation of chloride ions on Avalon Peninsula rivers in the winter months (2-3 fold increase) may also indicate road salt influence.

Skartveit and Gjessing (1979) found chloride to dominate the seasonal variation in anions in a Norwegian catchment and seasonal variation in chloride was governed by precipitation input, both quantities of precipitation and concentrations of chloride. Input-output budgets suggest no net retention of chloride in watersheds and the ion is largely unaffected by biological activity as well. Haines and Akielaszek (1984) found chloride levels to be highly variable and largely uncorrelated to discharge on New England rivers. They found chloride values to be stable over winter months with peaks in the spring and fall, after discharge had peaked.

Colour

Colour and discharge were positively correlated ($P \leq 0.25$) on 13 river systems (significantly on 5 rivers, $P \leq 0.05$) (Table 9). This relationship was not apparent on many of the south coast rivers (8 of 11 systems). Elevation of colour values in the spring (April 1982) were apparent on 16 rivers, while elevated colour values were also apparent in the late summer early fall (late September and late October) on many rivers. The fall peaks likely correspond to outwash of dissolved and particulate organics that have accumulated in the peatland headwaters during summer period of maximum plant growth, with subsequent microbial degradation.

For south coast rivers highest colour values were recorded in the September with declines in October. The hydrograph for gauged study rivers and hydrological data for unstudied rivers (Environment Canada 1982; 1983) demonstrated a growing increase in discharge from a low in mid September to a peak in the third week of October. Highest colour values in September likely correspond to the initial flushing of organic deposits while the October sample (see Fig. 10-17), taken within a day or two of maximum discharge for the fall, may be subject to a dilution effect. This might explain why there are few correlations between discharge and colour for south coast rivers.

Peaks in colour values are apparent in April 1982 relative to mid winter values, on 16 river systems. This is consistent with the findings of Scandinavian researchers (Johannessen et al. 1980; Bjarnborg 1983) who have reported that during snowmelt, colour values are usually highest at the point of maximum discharge and during the recovery period, when the runoff has opportunity to interact with exposed and thawed overburden.

Higher values of colour are presumed to be correlated to higher concentrations of organic acids during these hydrological peaks. This increase in organic acid concentration is contributing to the pH and alkalinity decline reported during hydrological events, along with dilution of terrestrially derived buffering ability (HCO_3^-) and the influx of acids of atmospheric origin. Lazerte and Dillon (1984) examined the seasonal changes in the proportion of strong mineral acids and weak organic acids entering a soft water Ontario lake, and found that during snowmelt, organics contributed minimally to total acidity. During low flows in mid-summer organic acids became dominant (75%) but on an annual basis contributed less than 15%. Haines and Akielaszek (1984) also found lowest colour values at peak spring discharge in New England rivers, and suggested organics acids contribute minimally to spring pH depressions. The contribution of organics to total acidity during snowmelt episodes is considered to be small relative to the accumulation of mineral acids in the snowpack. As snowmelt progresses and frozen ground thaws, the production of organic acids in the upper soil layer increases, and export to the watershed increases.

Scandinavian studies indicated that, while precipitation interaction with soils and vegetation increases the content of weak acids (organics and others) in receiving waters, there is no evidence to ascribe freshwater acidification to changes in organic content (Overrein et al. 1980). However, in Atlantic Canada, many of our freshwaters are strongly influenced by the abundance of organic soils and peatlands in the region and, at current levels of deposition, organics must be considered a major determinant of freshwater acidity.

Turbidity

Turbidity was postively correlated ($P \leq 0.25$) to discharge on eight rivers (significantly on one river, $P \leq 0.05$) (Table 9). Turbidity values ranged from a low of 0.1 J.T.U. (Grey River, September 1981) to a high of 7.8 J.T.U. (Colinet River, February 1982). The seasonal dynamics in turbidity largely followed that of the hydrograph with fall and spring peaks and low levels in late summer and mid-winter. There is a noticeable spring peak in most study rivers in April 1982 with an additional fall peak evident in September and October 1981. Turbidity is known to increase during hydrological peaks due to the increase in hydraulic turbulence in rivers resulting in a resuspension of sediment from river bottoms (bed erosion) and increased transport of particulates from the watershed by high runoff (slope erosion) (Gower 1980). While high runoff tends to dilute dissolved constituents it acts to increase particulate concentrations.

The amplitude in turbidity (low vs high values) ranged from a two fold increase (Gambo River, Pipers Hole River, Dolland Brook) to a 26 fold increase (Colinet River). Most rivers demonstrated an annual variation in turbidity in the order of a two to four fold increase (18 systems), and it is likely more frequent sampling would confirm a greater amplitude. Two of the Avalon Peninsula rivers demonstrated extremely high turbidities; Colinet River (7.8 J.T.U.-February 1982) and Biscay Bay (Back) Brook (7.2 J.T.U.-October 1981). These two rivers have small watersheds subject to rapid and extreme hydrological responses to precipitation events (see the hydrograph for

Rocky River as an example). The Colinet River watershed is subject to considerable land use and human disturbances while Biscay Bay (Back) Brook is characterized by a high proportion of soil barrens (62%) in the watershed. Both rivers are subceptable to considerable slope erosion and hydraulic turbulence.

Aluminum

The seasonal variability in aluminum for the 22 study rivers can only be evaluated over the last three study months. In most of the river systems the monthly pattern of aluminum availability is the same; highest values in March, lowest values in April, and May values being higher than those in April, but generally lower then those in March (see Table 5). Aluminum was found to be inversely correlated with discharge on 8 rivers (at $P \leq 0.25$) (Table 9), suggesting an apparent dilution effect. Aluminum values on Northern Peninsula rivers (Northwest Brook, Cloud River) were highest in April, which is the pre-snowmelt period for these two systems, however, data was not collected in May 1982 during snowmelt.

Most authors (Johnson et al. 1972, Skartveit and Gjessing 1979; Driscoll 1980b; Henriksen et al. 1984), studying trends in aluminum availability during snowmelt in high deposition regions, have reported an increase in concentration in association with snowmelt, although the timing of the rise and peak in Al varied considerably. Skartveit and Gjessing (1979) found aluminum mobilization and peak concentations in the later stages at snowmelt while others reported early peaks in aluminum in association with the highly acidic early meltwater. During snowmelt large quantities of H^+ are liberated into surface soils and, under saturated conditions, aluminum is rapidly mobilized and transported to streams and lakes. Spatial and temporal differences in the thawing of surface soils may play a large part in determining peak aluminum concentrations in the spring. Other authors (Brouard et al. 1983; Janicki and Cummins 1983) found considerable seasonal variation in aluminum concentrations in rivers and relationships with discharge and pH to be poorly defined. Haines and Akielaszek (1984) found aluminum to vary inversely with pH and alkalinity and to be positively correlated to discharge on two of nine rivers in New England.

Harvey et al. (1981) have suggested that, with meltwater with a pH of 4.5 or greater, H^+ will most likely be exchanged for base cations (Ca^{+2}, Mg^{+2}) while meltwater with a pH of less than 4.5 will be exchanged for Al. Rainfall pH in Newfoundland is highly variable and rarely is less than 4.5. It is doubtful meltwater is sufficiently acid to cause large scale aluminum weathering and significant elevation in association with snowmelt. Aluminum values in this study were low and were more clearly associated with organic content than with H^+ content.

In order to evaluate the trend in aluminum availability over the thirteen month study period, monthly data collected by Environment Canada (T. Pollock, pers. comm.) for two of the study rivers (Pipers Hole River, Rocky River) were examined from May 81 to May 82. In the two rivers, aluminum was found to be positively correlated to water colour ($P \leq 0.05$), and unrelated to river pH

(Fig. 17). On Pipers Hole River and Rocky River highest alumminum values were associated with seasonal peaks in water colour during the fall months (and summer months on Rocky River) and low values were characteristic of winter months (February and March). On these two rivers, aluminum variability was unrelated to river discharge. On Pipers Hole River the April '82 sample was collected two days after peak spring discharge and aluminum and colour were lower than mid-winter values, similar to the situation demonstrated for most of the south coast study rivers sampled near peak discharge.

Driscoll (1980a) and Lazerte (1984) reported that during snowmelt the proportion of inorganic aluminum species is increased, relative to the dominance of organic complexes, and may comprise as much as 50 to 80% of the ion. Driscoll (1980a) in the Adirondack Lakes Region of New York State found that the variability of monomeric organic aluminum followed the seasonal trends in organic carbon while the trends in monomeric inorganic aluminum was more clearly associated with stream pH and discharge.

Sample data evaluated for temporal variation were collected at monthly intervals. It is obvious that, in order to more clearly define aluminum variability in the spring, a more intensive monitoring program would be required. In addition studies on speciation of the ion would help contribute to an understanding of the magnitude of any spring "acid shock" effect in insular Newfoundland rivers.

RIVER STATUS

Sensitivity

An initial assessment of the sensitivity of the study rivers to acid precipitation can be made on the basis of bedrock geology. Geochemical properties provide the primary controls determining the acid neutralizing capacity of a watershed, and reflect the long term capacity to buffer acid deposition. Insular Newfoundland is characterized by heterogeneity in geological types, most of which have been classified as moderate to highly sensitive to acidification (Schilts 1981). Glaciation has tended to strip much of the overburden resulting in very limited and stoney soil cover in many regions. The ability of the various watersheds to buffer acid precipitation has been evaluated on the basis of bedrock geology (after Hendrey et al. 1980) and is listed in Table 10 (see also Appendix 2, Table 2.1). All study rivers are underlain by geological types of medium to low to no ability to buffer acid deposition, with the exception of Northwest Brook. Most south coast rivers (excepting Pipers Hole, LaPoile, and Conne) and the two northern peninsula rivers are dominated by highly sensitive granites and gneisses. The relationship between the sensitivity of underlying bedrock and resultant water chemistry, as evaluated previously, is quite evident.

Other terrestrial features also act to mediate the influences of acid deposition. These include soil properties (cation exchange capacity, texture, depth, drainage, etc.) and land form relief, vegetation, hydrology, etc. The ability of different terrain types to reduce acidity has been established on the basis of biophysical mapping, known or assumed soil characteristics, and

the bedrock evaluation of Schilts (1981) in Bangay and Riordan (1983). The resulting characterization for Newfoundland (the province as a whole) is as follows:

Total land area (Newfoundland and Labrador) 393,173 km^2

Ability to reduce acidity	Land area (km^2)	%
high	10,184	2.59
moderate	119,709	30.45
low	221,238	57.03
organics	39,042	9.93

It is apparent our region is dominated by terrain of moderate to low capacity to reduce incoming anthropogenic acidity. Organic terrain, while not classified with respect to acid neutralizing capacity, is acknowledged to reflect natural organic acidification, which is contributing to low pH and alkalinity in freshwaters associated with this terrain type. The organic terrain type was not classified as to acid sensitivity because it is not fully understood how peatlands are affected by or in turn can modify, mineral acid deposition.

Other terrestrial characteristics considered to be associated with acid sensitivity include the presence of coniferous forests and associated scrub vegetation, extensive barrens with bedrock outcrops and a large component of organic deposits or peatlands. The proportion of these terrain types in each river catchment can be interpreted from the distribution of land class types, as determined by biophysical mapping (see Table 2.2 in Appendix 2). Again the highly sensitive watersheds are dominated by softwood scrubs, barrens and organics. Less sensitive watersheds contain a high component of productive forest which is indicative of good soil development.

A number of indices based on current water chemistry have been employed to assess the relative sensitivity of freshwaters to acidification. The chemical composition of an aquatic system provides a measure of the capacity of the associated watershed area to neutralize acid imputs, considering both geochemical and biological processes, and under current levels of natural and anthropogenic acid loading. The alkalinity of water is probably the most reliable of these indices. The alkalinity of the study rivers has been previously discussed in relation to sensitivity categories established by the Ontario Ministry of The Environment. Similarly, calcium levels have been used to define the susceptibility of receiving waters, considering calcium to be an indicator of bicarbonate equivalence. While calcium levels may be useful to broadly categorize freshwaters, they give no indication of consumed buffering capacity due to acid loadings, and cation levels may be elevated somewhat in high loadings areas due to increased rates of weathering. Conductivity has also been employed as an index of acid sensitivity as it is a measure of the dissolved ionic solutes in a waterbody. However, conductivities are also useful to broadly categorize receiving waters and do not necessarily adequately reflect buffering capacity. In regions of strong marine contribution to freshwater, such as insular Newfoundland, conductivity may be an even less

reliable index. Alkalinity, calcium, and conductivity values for the study rivers are listed in Table 11 and summarized with respect to criteria used to define sensitivity to acid precipitation in Table 12. It must be remembered that these indices indicate sensitivity to long-term acidification only and do not address susceptibility to episodic effects.

The calcite saturation index (CSI) has been widely employed as an index of freshwater sensitivity to acidification (Kramer 1976; 1981). The CSI of water is the logarithm of its degree of saturation with respect to calcium carbonate. Consequently, water supersaturated with calcite will have a CSI greater than zero, while undersaturated water will have a CSI of less than zero (negative values). It has been proposed that a CSI value of greater than -2 indicates low to moderate susceptibility to acidification, CSI values of -2 to -3 indicate potential danger from acidification while CSI values of less than -3 indicate extreme potential for acidification with deleterious effects likely (Gorham 1976). CSI values have been calculated for this study by means of the following formula (after Thompson and Hutton, 1982):

$$CSI = \log (Ca^{+2}) + \log (HCO_3^{-}) + pH - \log K_2 - \log K_{SP}$$

where Ca^{+2}, HCO_3^{-} are molar concentrations of weighted means, $\log K_2$ (disassociation constant for carbonic acid) = -10.3, $\log K_{SP}$ (disassociation constant for calcite) = -8.3, and no corrections for temperature or ionic strength have been made.

The CSI for the study rivers, computed from weighted mean data, are also listed in Table 11 and summarized in relation to acid sensitivity in Table 12. Using the aforementioned criteria, it is apparent all rivers are characterized by CSI values of less than -3 indicating extreme sensitivity to acidification. Values ranged from a high of -3.83 on Northwest Brook to a low of -6.52 on its neighbouring system, Cloud River. These values are consistent with the scarcity of calcareous deposits in insular Newfoundland. Northwest Brook with the highest CSI, does have a proportion of calcareous deposits within its watershed (17% limestones and dolomites) but the system is still classified as sensitive. Some of the other rivers underlain by sedimentary geotypes, which are considered to be less sensitive than granitic and metamorphic bedrock, are also classified highly sensitive, reflecting the fact that these more readily weathered bedrock and surface deposits are also largely non-calcareous.

Clair et al. (1982) have used historical data to conduct contouring analyses of CSI values in the Atlantic provinces. Much of insular Newfoundland demonstrated CSI's at less than -3 and the CSI maps demonstrated a complex system of isopheths corresponding to the geological heterogeneity of the island. Ninety-five of 109 (87%) headwater lakes sampled in 1981 (Scruton 1983) had CSI values of less than -3. However, CSI values for three of the study rivers, (Rocky River, Pipers Hole River, Terra Nova River) using long-term average data (1966-79) from Clair and Whitfield (1983) are higher than CSI's calculated in this study. This can be related to lower pH's and alkalinities recorded in this study for those systems as calcium levels are more consistent with long-term averages.

Empirical Models

Several empirical models have been developed to predict the effects of anthropogenic acidification on freshwater chemistry. Empirical models have the advantage of integrating the process between acidic inputs and resultant outputs, with an understanding of the processes involved, but without the requirement for rigorous data collection and calibration. Empirical models are usually driven by a minimum number of variables, are simple computationally, and can be applied on a regional scale. These models were developed from the understanding that the interrelationships of acid (sulphate) loading, base cation concentrations, and surface water pH are quantifiable and can be used to understand and predict the chemistry of receptor systems (freshwaters).

River data collected from this study is presented in relation to two widely applied empirical models; Henriksen's Nomograph - developed from a data set of Norwegian lakes and Thompson's Cation Denudation Rate Model developed from data set for rivers in Atlantic Canada. A major assumption implicit in these two models is that the applied data represents steady state conditions. This study has demonstrated a wide seasonal amplitude in parameter concentrations and Thompson and Bennett (1981) and Thompson (1982b) have pointed out the year to year variability in pH and some other parameters for Newfoundland rivers. The use of weighted mean data is considered to best represent steady state conditions but it must be remembered this assumption relates only to the time period in question. This steady state assumption points out a deficiency in these empirical models; they are not dynamic and possess no time component. The predictive capacity of these models relates to the concentrations and quantities required to alter the status of receiving waters and do not determine the time frame involved.

Henriksen's Nomograph

Henriksen's (1980) model or nomograph evaluates data in relation to stages in the process of freshwater acidification, considering the process to be continuous and dynamic. The underlying premis of the model is that the process of acidification is analogous to the titration of a bicarbonate buffering system (of geochemical origin) with strong mineral acids (of atomspheric origin), more specifically with dilute sulphuric acid. This model is also based on equivalency between the major cations (calcium and magnesium), or calcium alone, to bicarbonate in non-acidified waters, and the use of present cationic concentrations to predict original alkalinity. Non-marine calcium and magnesium is plotted against non-marine sulphate with the ordinate representing geological determinants and the abcissa representing anthropogenic inputs of acid. The nomograph is divided into three sections, corresponding to segments in the titration of a bicarbonate buffered system. The first stage (Bicarbonate) is characterized by small decreases in alkalinity but maintenance of the bicarbonate buffering system. The second stage (Transition) is characterized by the loss of the bicarbonate buffering regime, severe fluctuations in pH, and episodic effects on biota. The final stage (Acid) is characterized by chronically low pH's, elevated levels of trace metals, and severe perturbation of resident biota. Wright (1984) has since used the nomograph to present data from 20 large rivers in Norway, plotting arithmetic

means from 12+ samples per river. He has demonstrated that the nomograph, originally developed as a lake acidification model, can also be applied to river data.

Before using this model it is important to review the assumptions regarding its application. Henriksen (1980, 1982a) stated explicitly that the nomograph may not be applicable to surface waters with significant concentrations of organic acids. This is because organics may be a major determinant of water pH independent of acid loading. In addition, laboratory analyses for cations will include organic complexes leading to an overestimation of true ionic concentrations.

In originally developing the model it was assumed no increase in base cations occurred in response to increased acid loadings. Other researchers (as reviewed in Harvey et al. 1981) suggested increased rates of weathering. Henriksen (1982c) addressed the issue and, although no universal trend was evident, he did propose a "base cation increase factor" for predictive purposes. This would indicate that, in regions with high acid loadings, present day cationic concentrations may overestimate original alkalinity.

The applicability of this or any model developed with data from one geographical area to other regions is a concern. Henriksen did apply his model to other geographical locales in a test of his original hypothesis; however, Bobée et al. (1982) and Haines and Akeilaszek (1983) found inconsistencies in application of the model to lake data from Quebec and New England, respectively. This has led to suggestions that it may be necessary to develop nomographs (and regression relationships) that are region-specific (Bangay and Riordan, 1983). Johnson (1985) modified the Wright-Henriksen model in assessing data from Georgia Bay rivers and found organic anions were important in achieving ion balances interpreting pH, and in modification of the chemical relationships in the model.

Volume-weighted mean data for the study rivers are presented on Henriksen's (original) Normograph in Fig. 20. The model suggests all rivers are in the Bicarbonate range indicating that, on a mean annual basis, these major river systems are not demonstrating serious effects from anthropogenic acidification. The model, however, predicts the correct pH for only 19 (79%) of the study systems. The five rivers with a pH of 5.3 or less, which the nomograph predicts should fall in the Transition range, fell in the Bicarbonate range. The obvious explanation is that there are other determinants, in addition to anthropogenic sulphate, controlling pH in these rivers. There is ample evidence to suggest organic contributions as a major controller of pH in these and other Newfoundland freshwaters (Scruton 1983, 1984a). The five rivers with a pH of less than 5.30 were classified as highly coloured (mean values ranging from 50 to 75 T.C.U.) indicating a large dissolved organic component. True ionic concentrations of calcium and magnesium may also be overestimated as the laboratory determinations would have included organic-cation complexes.

Thompson's Cation Denudation Rate (CDR) Model

Thompson(1982b) has developed a model, the CDR Model, relating the pH of a river to the atmospheric loading of acids (sulphate) and the rate of weathering of cations from a watershed by runoff. The Thompson model derives from charge balance, that is the sum of cations approximates the sum of anions after correction for seasalt. A plot of excess sulphate vs the sum of base cations yields a series of lines representing constant bicarbonate concentrations. Assuming a constant partial pressure of CO_2, each line also represents a constant pH. The figure becomes a plot of cation denudation rate (CDR) in $meqm^{-2}\ yr^{-1}$ (cation concentration x discharge ÷ watershed area) versus the atmosphere loading of sulphate in $meq\ m^{-2}\ yr^{-1}$ (excess sulphate x discharge ÷ watershed area). To allow the model to be more universally applicable a constant runoff rate of $1m\ yr^{-1}$ can be assumed and the sum of non-marine base cations is applied against excess sulphate concentrations.

A number of important assumptions also apply to the use of this model. All excess sulphate must be of atmospheric origin and must flow through the watershed without being retained on a net (annual) basis. We have demonstrated geological sources of sulphate in a few Newfoundland lakes (Scruton 1983) and there appears to be seasonal flux in sulphate flow through some study river watersheds. However, the use of mean data (over 13 months) assumes this flux is accounted for and the large watersheds included in this study should also reduce the contribution of small pockets of geological sulphate (as pyrite, gypsum deposits). Another assumption is to the constancy of PCO_2 (partial pressure of CO_2) and significant variation in PCO_2 in surface waters are well known (EPA 1983). Thompson explicitly assumes the CDR is independent of the rate of acid loading and is variable only with discharge. Henriksen (1982c) and Haines and Akielaszek (1984) have suggested that CDR is not constant in all cases, and can be accelerated in high acid loading regions.

There is also the concern as to whether the CDR model can be applied to freshwaters with a preponderance of organic acids. For the original model development, Thompson (1982b) tested the model in relation to some highly coloured rivers in Nova Scotia. The pH of these rivers was thought to be dominated by organic determinants but, in applying the CDR, Thompson felt the low river pH was explained by the considerations of inorganic chemistry used in model development. Recent reviews of the CDR (EPA 1983; Bangay and Riordan 1983) suggest the model may not be applicable to situations where organic acids strongly influence pH.

In Table 6 it can be seen that CDR's calculated for this study were appreciably higher than those calculated by Thompson (1982b) in model development and higher CDR is not always coupled to higher sulphate loads. A portion of this difference in CDR can be explained by the higher runoff during the study period.

The poor agreement of our data with the CDR model would suggest either some analytical problems or possibly that inorganic chemistry does not fully explain the relationships between cations, sulphate and pH in the study rivers. As this model derives from charge balance, poor agreement of our data with the model would initially suggest some analytical errors. As previously indicated

these is a low bias for chloride in the data which, coupled to a detection limit of 0.2 mgL^{-1}, could greatly bias the computation of contribution of marine cations leading to an overestimation of non-marine cations. This would be particularly true for non-marine sodium because of the high Na:Cl ratio in sea water (0.556:1 by equivalence). The lab was also determined to be biased low for sulphate and pH, two other driving variables of this model. Cation exchange of marine sodium for calcium has been demonstrated in two Newfoundland watersheds, on the Isle aux Morts River (Thompson 1982a) and on Northeast Pond River (Thompson 1983). Although there is no concrete evidence of this phenomenon occurring in the data set, seasonal cation exchange involving marine sodium may be occurring to some extent and contributing to overestimation of cations produced by H_2CO_3 and H_2SO_4 weathering.

The underlying assumption of the equivalence of non-marine cations to excess sulphate and bicarbonate was not achieved in this study and, comparing weighted means, there was always a deficiency in anions. As indicated in the discussion on quality assurance it is likely organic anions are a major constituent of the water chemistry in the study rivers, although it is not possible to quantify this component and include it in the charge balance for all data. A recent survey of south coast rivers in 1984 has employed the calculation of organic anions from DOC after Oliver et al. (1983). In samples from 20 rivers, water colour ranged from 12.5 to 75.0, DOC from 3.6 to 11.9, and organic anion concentration ($COOH^-$) from 35.8 to 112.7. In many of these rivers, organic anions ($COOH^-$) were determined to be the dominant non-marine anionic constituent. This approach has confirmed the importance of organics as an anionic constituent and the need to consider its contribution to the acid/base chemistry of coloured waters. Also, in assuming a significant contribution of organics to the freshwater chemistry of these rivers, it is probable that some of the cations determined in analyses were present as organic complexes. The presence of these complexes would further overestimate the true ionic concentrations that would result from carbonic and mineral acid weathering.

In the original model development, Thompson used sulphate loading data for 1973, which was a high loadings year for the Atlantic region. For 3 of 4 rivers with comparable data, sulphate loading over the study period was equal to or lower than 1973 values, despite the appreciably higher flows (higher runoff) over the study period. For Pipers Hole River, sulphate loadings were higher during the study period (+14%) while runoff was 45% higher. In most of the study rivers there is evidence of a fall peak in colour values, for one or more months, which must be considered to represent similar peaks in concentration of organics. High runoff recorded in the fall months (particularly in October) would suggest a period of very high loadings of natural acids to receiving waters. In many instances excess sulphate concentration also rises likely due to high precipitation and flushing of biogenic sulphur. The data suggest a higher contribution of organics to the study systems over the study period than in normal years. This is also largely substantiated by comparing weighted mean colour values for this study with median colour values for data over the period 1965-80 (see Table 13). The indication is that, under a situation of high loadings of anthropogenic acids, inorganic chemistry is the major determinant of the acidity of receiving waters. In scenarios of more moderate loadings and large inputs from

terrestrial organic reserviors in the watershed, organic acids may play an appreciable role in determining the acidity of soft water rivers.

Thompson (1983) has also provided some evidence of this variability. She conducted factor analyses on a set of data for the Mersey River, a highly coloured (mean colour of 50) river in Nova Scotia. The results of this analyses indicated that the pH of the river was dominated by organic compounds, i.e. the first factor was highly related (positively) to colour, total organic carbon and aluminum and negatively to pH. Conversely the CDR model had indicated the pH of the Mersey River was sufficiently well explained on the basis of inorganic considerations alone. This inconsistency may be evidence of the year to year variability in importance of mineral and organic acidity to rivers in Atlantic Canada. However, the poor agreement of our data with the CDR model, allowing for possible analytical problems, does support the concerns of other reviewers (Bangay and Riordan, 1983; EPA 1983); that is that the model may not be applicable to freshwaters of high organic content.

Clair and Whitfield (1983) have conducted some time series analysis on water chemistry data for rivers in Atlantic Canada, to determine if acid precipitation is affecting the region. Long term records for 11 rivers, including four from Newfoundland (three of which were included in this study - Rocky River, Terra Nova River, Pipers Hole River), were fitted using Box-Jenkins time series models. Trends in pH were all either stationary or decreasing for rivers considered sensitive to acid precipitation. Isle aux Morts River, Rocky River, and Terra Nova River demonstrated a decreasing trend while Pipers Hole River was stationary. Trends in sulphate could not be generalized. Isle aux Morts River and Rocky River demonstrated stationary trends in sulphate, Terra Nova River demonstrated an increasing trend, and the model did not fit the data for Pipers Hole River. The authors feel conceptual models used to evaluate acidification effects (pH decline with coincident elevation of sulphate) did not adequately explain the long term trend in water chemistry for Atlantic Rivers.

Thompson and Bennett (1981) have shown that climatic factors could cause significant variation in the rate of acid deposition to different watersheds, and this variability can be pronounced in regions on the fringe of high acid deposition, such as insular Newfoundland. As an example they present the pH and sulphate history (volume-weighted mean annual values 1966 through 1978) for Rocky River on the Avalon Peninsula (see Fig. 21). Trends in river acidity (pH) are closely followed by trends in SO_4^{2} concentrations. These year-to-year trends are thought to be unrelated to variations in emissions at source but rather reflect variations in local or regional climatic factors. The fact that pH rises when SO_4^{2} loading decreases indicates the dynamism of geochemical response to acid loadings. The Rocky River is considered not seriously affected by acid deposition (chronically acidified) by virtue of the recovery in pH in years of low sulphate loading.

POTENTIAL EFFECTS OF LOW pH ON RESIDENT FISH

The major objective of this survey was to evaluate the spatial and temporal (seasonal) variability in river water chemistry and subsequently

determine if chronic or episodic acidification of these systems is occurring. A second major objective was to determine if seasonal excursions in pH and other parameters are of sufficient magnitude to adversely effect resident biota, in particular fish communities. This section will evaluate the timing of pH depressions in relation to the occurrence of sensitive life stages of resident fish. The wealth of literature on pH and aluminum toxicity will be examined to define the tolerance limits of resident species, and to determine if the potential exists to adversely affect fish production in Newfoundland rivers.

The freshwaters of insular Newfoundland are characterized as having relatively low diversity in fish fauna and communities are usually salmonid dominated (Scott and Crossman 1964). The major species of concern in the study rivers, from a commercial and recreational exploitation point of view are Atlantic salmon, Salmo salar (anadromous and landlocked) and brook trout, Salvelinus fontinalis (resident and sea run). Brown trout (Salmo trutta) may also contribute to the recreational fishery in many Avalon Peninsula rivers.

Atlantic salmon are present in some 160 major river systems and hundreds of smaller streams in the province. In 1983 there were about 5000 licences issued to commercial salmon fishermen, and total salmon landings for the last ten years have averaged close to 1600 metric tons annually, representing about 90% of the total commercial catch for the Atlantic Provinces (Rex Porter, Department of Fisheries and Oceans, Fisheries Research Branch, P. O. Box 5667, St. John's, Newfoundland A1C 5X1, pers. comm.). The landed value of these fish, in 1983 dollars, is close to 5.4 million dollars. In addition, 23,000 resident and non-resident angling licences were issued in 1983 and about 45,000 fish taken, amounting to 30% of the recreational fishery for Atlantic salmon in Atlantic Canada. This fishery is estimated to have a value of close to 14.8 million dollars (R. Porter, pers, comm., Department of Fisheries Oceans, Fisheries Research Branch, P. O. Box 5667, St. John's, Nfld., A1C 5X1), although this figure is subject to considerable dispute. A major survey of recreational anglers in 1980 estimated that 102,000 Newfoundlanders and 4400 non-residents fished in the province that year (Fisheries and Oceans 1984). About 90% of the residental anglers spent some time pursuing the various trout species and a total of 8.9 million freshwater and anadromous fish were taken. Brook trout, rainbow trout and brown trout accounted for 91% of the catch by number, or 6.9 million fish. The total angling effort in 1980 (resident and non-resident) was 1.9 million rod days, and total expenditures were in the order of 20 million dollars.

pH

It is important to note that the ability to tolerate low pH is highly variable between species and within species, according to differences between population and strains, while different life stages also demonstrate wide variability in relative sensitivity. Many other environmental variables influence the relative effects of low pH (Kwain 1975; Howells et al. 1983; and others). Accumulative research in Scandinavia (Overrein et al. 1980) and in North America (Beamish 1976; Haines 1981a) has led researchers to conclude that the relative tolerance of salmonids to low pH is as follows:

relatively tolerant	brook trout	(Salvelinus fontinalis)
↑	arctic charr	(Salvelinus alpinus)
	brown trout	(Salmo trutta)
	Atlantic salmon	(Salmo salar)
↓	lake trout	(Salvelinus namayacush)
relatively sensitive	rainbow trout	(Salmo gairdneri)

The effects of low pH on reproduction and fertilization has been suggested as a contributing factor in recruitment failure in acidified freshwaters (Harvey et al. 1981), although experimental evidence for salmonids is lacking. Johnson and Webster (1977) found brook trout females to avoid spawning in water of pH 4.5 and less while Menendez (1976) has found fertilization of trout eggs to undergo a marked reduction at pH 5.0. Daye (1981) has reported a decrease in the proportion of fertilized salmon ova in acid water. Possible modes of influence include adverse effects on oogenesis, fertilization (viability of sperm) and spawning behaviour (including avoidance).

Most recent and ongoing toxicity experiments have been directed at early stages of fish, acknowledged to have a greater sensitivity to low pH and toxic metal species than adults (Bergman et al. 1985). The effects of low pH on survivability of embryos of salmonids is well documented and there is ample evidence of considerable variation in tolerance as reported for the same species. Johansson et al. (1977) found brook trout embryos showed little effect of acidity until pH 4.5, while Atlantic salmon demonstrated increased mortality at pH 5.0, and for both species, mortality at the same fry stage was greater than in pre-hatching stage. Trojnar (1977) found brook trout egg survival to be high (76-91%) over the pH range 4.6-8.0 and he also observed earlier hatching of eggs in low pH water (pH of 4.65 vs 4.95, 5.04 or 8.07). Conversely Menendez (1976) reports a reduction in egg viability of pH's approaching 5.0 for brook trout. Leclerc et al. (1984) examined the effect of low pH on brook trout in Quebec and found egg mortality in response to low pH to begin as early as the first cleavage stage and reached 30% at pH 4.8 and 60% at pH 4.4, within 35 days of exposure. At pH 4.2 mortality reached 100%. They conclude that acid tolerance of brook trout as reported in the literature (in the pH range of 4.2 to 4.8), may be too low for Quebec populations and the level may likely be well over pH 5.0.

Bua and Snekvik (1972) observed high mortality of Atlantic salmon eggs between pH 5.0 and 5.5, and there was substantial annual variation in relative toxicity. Petersen et al. (1980) found that hatching of Atlantic salmon embryos was delayed or prevented if exposed to acid water (pH 4.0 to 5.5) and normal hatching resumed at pH levels of 5.6 to 6.8. The observed effects are hypothesized to be due to inhibition of the hatching enzyme, chorionase, whose activity has been demonstrated to be pH dependent. pH minima in Nova Scotian streams often coincides with the period of embryo hatching (April) resulting in mortalities or delays in hatching. LaCroix (1985) found the hatching success of Atlantic salmon embryos in streams of pH 4.6 to 6.5 to be correlated to pH and the LL50 to approach pH 4.7. At pH 5.0 hatching success was about 75%. Daye (1980) found salmon alevins, prior to emergence, demonstrated lethal

levels of pH of 4.5 and less. Alevins were less tolerant than embryos and acclimatization to low pH conditions did not occur.

Farmer et al. (1979) found post emergent salmon fry (3-4 weeks after converting to exogenous feeding) to be highly sensitive to low pH. A pH of 5.0 caused 19-38% mortality while a pH of 4.3 caused 50% mortality. Growth of alevins was reduced at pH of 5.0. La Croix et al. (1985) have conducted some in-situ bioassays to investigate the effects of low pH on post emergent Atlantic salmon fry in a soft water, acidic Nova Scotian River. Fry exposed to low pH water (mean of 5.0) demonstrated accumulative mortality of 70% after 30 days as opposed to 4% in fry exposed to pH of 6.1 Surviving fry at pH 5.0 appeared to develop a tolerance after 25 days and demonstrated similar growth to fry reared in pH 6.1, and the authors suggest this acquired tolerance may depend upon reaching a minimum size. The authors conclude that fry mortality during transition to exogenous feeding is likely responsible for recruitment failure and stock declines observed in many acidic Nova Scotian salmon rivers. The low limit for successful transition of post emergent salmon fry appears to be at pH 5.0.

Saunders et al. (1983) and Johnston et al. (1984) investigated the influence of low pH on smoltification in Atlantic salmon. Salmon smolt exposed to pH 4.2-4.7 demonstrated lower survival than those reared at higher ambient pH. Smolt exposed to low pH demonstrated reduced salinity tolerance and lowered ATPase activity while ionic regulation was impaired. The authors conclude that smoltification did not proceed normally in parr exposed to low pH and smoltification could be inhibited in chronically acid rivers. Norwegian researchers have recently found the smoltification stage of salmon to be particularly sensitive to the toxic interactions of pH and aluminum (see following section).

White (1940) and Wilder (1952) have observed a smolt stage in the freshwater cycle of sea trout (Salvelinus fontinalis) life history indicating that trout may undergo similar physiological changes to salmon prior to moving to salt waters. Jensen and Snekvik (1972) report that sea-run brown trout were less tolerant than freshwater brown trout to low pH suggesting physiological change during "smoltification" as a explanation.

Daye (1980) has demonstrated that Atlantic salmon cannot develop a resistance to acidity at the embryo, alevin or fry stages. Johansson et al. (1977) have also shown that salmon, able to survive hatching in low pH regimes, showed substantially higher mortalities at the fry stage than those reared in less acid environments, suggesting the effects of low pH can be accumulative. There is also probable long-term (through natural selection) acclimatization to naturally acid water (Schofield 1976a) and acclimation of brook trout populations to naturally low pH (bog) waters is well known in insular Newfoundland. Schofield (1979) cautions that acidification may be proceeding too rapidly for adaptation or natural selection to work effectively in the natural environment.

A consideration in exposure of salmonids to acid shock is the ability of fish to seek out refugia from potentially lethal pH/aluminum levels, and the availability of refugia in lentic and lotic habitats. There is of course

differences in the ability of different life stages to seek out refugia in lakes or alternative streams during episodes. Observations by several researchers, as reported in Grande et al. (1978) and Rosseland (1985), indicate brown trout, brook trout, and Atlantic salmon may be able to detect and spawn in localities with more favourable water quality. Recently Gunn and Noakes (1985) have demonstrated the ability of brook trout sac fry to avoid lethal levels of H^+ (pH) and aluminum in the lab, suggesting that this life stage may be able to avoid acidic runoff water if suitable chemical refugia is available nearby. Watt (Department of Fisheries and Oceans, Fisheries Research Branch, P. O. Box 550, Halifax, N.S., B3J 2S7, pers. comm.) has suggested establishing and maintaining pH refugia in acidic Nova Scotian salmon rivers, through liming, as a means of maintaining genetic integrity until emissions controls allow a more permanent solution.

Aluminum

It is now generally conceded that declines in fish populations as a result of acidification, is a function of low pH and coincident elevated concentrations of metals; most notably aluminum and, to a lesser extent, manganese (Harvey et al. 1981; EPA 1983). Comparisons of controlled laboratory experiments to in-situ field experiments or observations led most researchers to conclude that there were additional toxic agents operative in acidic surface waters other than H^+ (Muniz and Leivstad 1980; LaCroix et al. 1985). While the interactions of pH, aluminum and other agents are complex, the presence of toxic aluminum generally acts to raise the lower limits of pH sensitivity.

Aluminum has been demonstrated to be toxic to fish in concentrations as low as 0.1 to 0.2 mg L^{-1} (100-200 $\mu g\ L^{-1}$) (Baker and Schofield 1982; Schofield and Trojnar 1980). Toxicity of aluminum to fish depends upon the speciation of the metal and organic chelation has been demonstrated to reduce the toxicity of Al (Baker 1982; Baker and Schofield 1982). Aluminum is considered to be at least two times as toxic to brook trout in its inorganic form as in its organic form (Driscoll et al. 1980). Toxicity of monomeric aluminum is also variable but is particularly toxic over the pH range 5.0 to 5.4. Speciation is determined largely by pH and the availability of ligands to complex with aluminum. However, organic aluminum predominates among various species in natural waters (Baker and Schofield 1980) and evidence would suggest the same is true for insular Newfoundland's freshwaters (Scruton 1983).

Clair and Komadina (1984) reported Al concentrations in organic rich soft water rivers in Nova Scotia to be correlated with DOC levels and there was little inorganic (labile) Al in brown waters. However, the authors caution more study is needed to determine speciation of Al during acid shock conditions, either during snowmelt or heavy rains. Aluminum may become disassociated from organics and sediments and be present in the labile form during episodes (Driscoll 1980a). The availability of organic ligands may also change dramatically during episodes.

Much of the initial work on aluminum toxicity was elucidated on brook trout from the Adirondack Mountains in New York State. Schofield and Trojnar (1980) initially reported on mortalities in brook trout (adult, larval and

yearling) during spring snowmelt. pH minima was relatively safe (5.0) but aluminum concentrations were significantly elevated (0.39 mg L^{-1} Al). Baker and Schofield (1980) have found aluminum toxicity for brook trout to be most influential over the pH range 5.0 to 5.5. From pH 5.5 to 6.5 Al solubility decreases and its toxicity is reduced as a result. Brook trout alevins adopting autonomous feeding are most sensitive (threshold approaching 200 $\mu g\ L^{-1}$ Al or less at pH 4.5 to 5.5) after which the sensitivity of juveniles to low pH/high Al decreases. Aluminum has been demonstrated to have little influence on pH toxicity for salmonid embyros. Baker and Schofield (1982) found that the presence of Al seemed to enhance survival of eyed trout eggs at pH < 5.0 and a slight increase in mortality was seen between pH 5.0 and 5.5.

Schofield and Trojnar (1980) have found the relative toxicity of pH and Al to brook trout alevins to vary considerably and Al toxicity to trout is pH dependent over the pH range 4.4 to 5.2. At pH 4.0 the TL50 does not vary according to Al concentration (over 100 to 1000 $\mu g\ L^{-1}$ range), suggesting the toxic effect is primarily due to acidity. At pH 4.4 Al toxicity becomes apparent as TL50 for alevins exposed to 100 $\mu g\ L^{-1}$ is 10 days as opposed to 2 days for those exposed to a concentration of 500 $\mu g\ L^{-1}$. At pH from 4.9 to 5.2 aluminum toxicity predominates H^+ toxicity. These studies led Schofield and Trojnar (1980) to suggest that aluminum levels, rather than pH alone, may be the primary factor limiting trout survival in Adirondack lakes.

Comparable studies on the interactions of pH and aluminum toxicity to Atlantic salmon (Salmo salar) have recently been published. Rosseland and Skogheim (1982) have conducted experiments to determine the relative sensitivities at different life stages of Atlantic salmon to low pH/labile aluminum combinations. Fish were exposed to pH 4.90 and concentrations of labile aluminum varying from 130 to 142 $\mu g\ L^{-1}$ for 64 hours. Eyed eggs showed no mortalities under the experimental conditions, while yearlings (1^+) and presmolts (2^+) demonstrated increasing mortality and sensitivity with increasing Al concentrations, the presmolt being more sensitive than yearlings. Henriksen et al. (1984) also demonstrated the hightened sensitivity of salmon to low pH during smoltification. Hestagen and Skogheim (1983) have reported the mortality of presmolts at pH 5.15 to 5.50 and labile aluminum concentrations of 30-55 $\mu g\ L^{-1}$. Skogheim et al. (1984) have recently reported on the death of adult Atlantic salmon as caused by acidified, aluminum rich water in Norway. Adult salmon, rentering rivers after one or more winters at sea, also experience physiological stress in adaptation to freshwater which likely influence their tolerance of low pH and high Al conditions.

Van Coillie et al. (1983) have found that aluminum is clearly more toxic to juvenile Atlantic salmon (aged 1^+) than to brook trout (aged 1^+). In avoidance experiments, salmon (aged 2^+) showed stronger avoidance reaction to elevated aluminum levels than for moderate acidity. Brouard et al. (1982) suggest that the threshold in toxicity of labile aluminum for juvenile Atlantic salmon in Quebec might be in the order of 100-150 $\mu g\ L^{-1}$ at pH at 5.0 to 5.5. Leivstad (1985) and Leivstad et al. (1985) evaluated the sensitivity of different life stages of Atlantic salmon to high Al, low pH exposure and found smolts to be the most sensitive stage followed by swim-up fry, parr (1+) and start feeding fry, respectively. Fish acclimatized to soft water, low pH

conditions showed no toxicity to H^+ alone above pH 5.0 and toxicity over the range pH 5.0 to 5.7 was correlated with labile Al levels.

The accumulative research on pH and aluminum toxicity to various early life stages of salmonids indicates that mortality of salmonid eggs seems to be mainly related to pH (H^+). After hatching the toxicity seems to be an effect of both pH and aluminum, with Al toxicity increasing with increasing age. Authors have also cautioned that sensitivity to pH (and aluminum) shock may increase over the winter partly as a consequence of declining condition due to ceasation of feeding (Falk and Dunson 1977).

Habitat Considerations

In considering the magnitude of pH episodes in insular Newfoundland, it is important to remember that samples collected in this study were taken near the river mouth in order to obtain a sample that would reflect the average character of the entire drainage system. Much of the available salmonid spawning and rearing habitat is associated with the upper reaches of these rivers, primarily in the lower order tributaries and streams (first, second and third order). It is generally accepted that headwater streams are more sensitive to the effects of acid deposition and acidify more quickly and to a greater degree than downstream reaches (Potter et al. 1982). Characteristics of headwater streams that renders them particularly sensitive to acidification include glacial removal of overburden (with available calcareous materials) and their hydrologial nature (high flushing rates, rapid runoff, high gradient, limited standing water storage potential, etc.). It follows that episodes evident on the mainstem of study rivers will be even more pronounced in the headwaters where the acid sensitive early life stages of salmonids may be exposed to greater extremes in pH and aluminum than this study would suggest.

It must also be pointed out that it is likely that resident brook trout, and possibly landlocked salmon, may be the only species utilizing some of the extremely sensitive habitats high in headwaters of the study rivers, due to inaccessibility to anadromous salmon. Kelso and Minns (1982) have suggested that trout may be the species most affected by continuing widescale acidification due to association of the species with the most sensitive habitats, despite the relative tolerance of this salmonid to low pH. Recently relic arctic charr (Salvelinus alpinus) populations have been confirmed in the headwaters of Northern Peninsula and south coast rivers and the species likely utilizes headwater streams for reproduction (unpubl. data).

Studies on New England salmon rivers found pH/aluminum concentrations on second and third order streams to be within safe limits for salmon, even during peak discharge (Haines and Akielaszek 1984). However, first order streams, containing 20-40% of available habitat, demonstrated pH/Al levels potentially toxic to early life stages. Haines (1981b) also found considerable watershed variability in pH on a Conneticut salmon river (West River). pH varied from 4.9 to 5.2 on two headwater streams to 7.6 on the mainstem near the mouth. Gjessing et al. (1976) have also demonstrated the variation in pH between a large river system and a smaller tributary. The annual variability in pH was much less on the major drainage system (0.65 units) than on the tributary which

demonstrated extreme and rapid pH changes (1.65 units annual variability). pH depressions and minima were much more extreme on the smaller tributary. Jeffries et al. (1979) also found smaller streams in Ontario to undergo a greater change in pH due to snowmelt than did larger rivers.

In addition to broad scale differences in the sensitivity of salmonid habitat to acidification there are also microhabitat influences. La Croix (1985) reports that pH exposure of salmon embryos may be site specific owing to changes and variability in the redd environment. In Nova Scotia streams he found the mean pH in redds was usually slightly higher than surface water pH, and the author suggested this could be due to some buffering capacity in the substrates in addition to differences in the renewal time of water. Haines and Akielaszek (1984) found intragravel pH to be higher than stream samples, with the difference being the smallest during the peak discharge in April. Swim-up fry may be particularly vunerable to acid shock because, not only are they undergoing considerable physiological stress adopting to exogenous feeding, they are leaving the confines of the substrate where some localized buffering capacity may have existed. In addition, during snowmelt, post-emergent fry may be exposed to harsh physical conditions including increased flows and turbulence, high turbidities and temperatures, etc. which further contribute to chemical induced stress (Marmorek et al. 1984).

The spawning period for anadromous salmon in Newfoundland is variable from river to river but most spawning occurs, in average years, in the first two weeks of November (R. Porter, C. Bourgeois, pers. comm., Department of Fisheries and Oceans, Fisheries Research Branch, P. O. Box 5667, St. John's, Nfld., A1C 5X1), and occasionally earlier. Dalley (1978) reported a peak in spawning activity on the Northeast River (Avalon Peninsula) on November 10 in 1974. Fall pH depressions in 1981 were variable as to timing but December was the single month in which most rivers (14) demonstrated fall minima. The fall peak in the hydrological cycle in 1981 occurred in October for virtually every river, but a extended high flow period was evident on many systems from early to mid October to the end of December. The long-term hydrological record for many systems in central, eastern and southern Newfoundland and the Avalon Peninsula suggests extreme variability in the timing of peak flows but mid-November to the end of December is most frequently the peak flow period in the fall months (Environment Canada 1980). The historical hydrological record would indicate (in most years) that most salmon spawning would probably have occurred prior to fall pH minima, resulting in salmon embryos most frequently being exposed to the most acid conditions. In the fall of 1981 the timing of pH minima was highly variable, but the hydrological record suggests a late October peak prior to spawning in most gauged study rivers. Low pH conditions in the early fall, prior to spawning, could potentially cause mature salmon to avoid preferred habitat in some spawning streams. pH levels in the study rivers are generally within the range of tolerance of salmon embryos, although pH's of less than 5.00 were recorded in fall months on four rivers; in November on Indian Bay Brook, in December for Gambo and Terra Nova Rivers, and in both October and December on the Cloud River. The true nature of exposure of spawners and embryos in the fall to acid conditions in not clear, particularly in critical headwater areas.

Brook trout spawn in the fall from mid-October to mid-November when water temperatures reach 4.4°C to 9.4°C (Wiseman 1969). In most years it is likely trout have spawned prior to peak fall discharges (with associated maximum pH depressions) but this may not have been the case in 1981.

Incubation of salmon embryos to hatching in insular Newfoundland generally last from 4 to 5 months depending upon water temperatures. Observations at Noel Paul's Brook and Black Brook Incubation Facilities indicates that hatching usually precedes fry emergence by 4 to 5 weeks (C. Bourgeois, T. Nicholls, Department of Fisheries and Oceans, Fisheries Research Branch, P. O. Box 5667, St. John's, Newfoundland A1C 5X1). Hatching usually occurs during the increase in flows to spring maximum associated with snowmelt and rising water temperatures. Eight years of observation at Noel Paul's Brook suggests hatching precedes peak flows by several days to 2 weeks or more. This would suggest that embryos ready to hatch and alevins in the redds, are exposed to the most extreme (acid shock) conditions in the spring.

pH minima in the spring of 1982 are sufficiently low (<5.0) on four south coast rivers to potentially influence the successful hatch or viability of alevins. In addition, eighteen of the study systems demonstrated a pH of less than 5.5 in April 1982. Peterson et al. (1980) observed 37 to 40% mortality of embryos at prolonged exposure to pH 5.0 and 4.5, respectively, while delayed hatching (which contributes to mortality) was observed at pH's of 5.5 or less. Two rivers (Gambo, Terra Nova) demonstrated a pH of 5.5 or less for both April and May 1982. It is probable that an extended period of pH less than 5.5 occurred on several south coast rivers (pH values for May 1982 are unavailable for several rivers) as well, indicating prolonged exposure to pH's with the potential to inhibit hatching. Again chemical stress in smaller spawning streams is likely more severe.

Fry emergence in Newfoundland rivers has also been demonstrated to be extremely variable. Observations at Noel Paul's Brook indicate the bulk of fry emergence has historically been between June 10 and 25 when water temperatures reach 10-20°C, although earlier emergence occurred in 1971 (June 5-6) and 1979 (June 5-6) (O'Connell et al. 1983). Peak fry run at the Black Brook Incubation Facility (Indian River) in 1984 was observed from the 13 to 23 of June (Anon. 1985). Fry emergence on a spawning channel on the Avalon Peninsula was observed to peak on June 3 (1982), from May 30 to June 2 (1983) and from June 2 to 10 (1984) with emergence commencing as early as May 10 in 1982 (Meaney 1983, 1984, 1985).

Available observations on fry emergence and the hydrological record suggests peak fry emergence occurs from 2 to 4 weeks or more after the major snowmelt. This would suggest that the life stage of salmon considered most sensitive to low pH, post-emergent fry adopting to exogenous feeding, may not be exposed to acid shock conditions occurring at peak spring discharge. However, long-term hydrological monitoring by Environment Canada indicates that in some atypical years, peak runoff can be delayed into late May-early June, or high runoff is maintained for an extended period due to high precipitation. For example, this type of situation occurred on the Rocky River in 1973, and consequently the low pH (4.90) for that year was recorded on June 11 (Scruton

1984b). In certain years a late peak in runoff could coincide with the occurrence of post-emergent salmon fry.

Counting fence and fyke net operations provide some information on the timing of downstream runs of salmon smolt (Moores and Ash 1984). Porter (1975) has stated that smolt runs in most Newfoundland rivers occur in May and June, when water temperatures reach 5 to 10°C, and can last several weeks. The process of smoltification, when salmon are particularly sensitive to chemical stresses, begins sooner with water temperature and photoperiod considered major environmental stimuli (Saunders and Henderson 1970). Data for the Exploits River indicates peak smolt runs occur in early and mid June, with the run commencing in May (O'Connell et al. 1983). Baie du Nord River, on the south coast, demonstrated peak smolt runs in late May (24-30) in 1953 and mid May (16-22) in 1954. Smolt runs on Western Arm Brook, as an indicator of timing on Northern Peninsula rivers, peaked mostly in mid-June over the period 1971 to 1979. The smolt run commenced when temperatures reached 7°C, peaked at 10°C and lasted up to 40 days (Chadwick 1981).

There is ample evidence to indicate that presmolts in insular Newfoundland are exposed to spring acid shock conditions. pH minima on eighteen study rivers in April are less than 5.5, although coincident elevation of dissolved aluminum was not established. The Norwegian experience indicates that pH toxicity to smolts over the range of less than 5.5 is usually in association with significant labile aluminum concentrations. Saunders et al. (1983) suggests that pH alone may only be toxic to smolts below pH 4.7, a situation which existed (probably transiently) on only two rivers. The nature of exposure to labile aluminum has not been established in this study.

Anadromous brook trout populations are abundant in insular Newfoundland but little work has been conducted on their life history (O'Connell 1984). Wiseman (1969) and O'Connell (1984) have reported that, for the most part, most trout move to salt water in the spring in Newfoundland, generally late April through early June. Large numbers of trout have been recorded moving downstream in association with salmon smolt runs suggesting similar timings to their seaward migrations. White (1940), Wilder (1952), Smith and Saunders (1958) have reported seaward trout movements on rivers in response to rising water temperatures, mostly over the range 5° to 11°C. Movement was also in association with, but not correlated to, rising water levels. Brook trout are the most acid tolerant of salmonid species, particularly after fry have successfully adapted to exogenous feeding, but physiological modifications during adaptation to sea life may increase the sensitivity of fish moving to salt water.

River Status in Relation to Atlantic Salmon

Watt (1981) has established four categories of river (based on mean annual pH) to evaluate the current and potential impacts of acidification on Nova Scotian salmon rivers. These categories were determined on the basis of perceived significance of these pH levels to salmon recruitment and production. The categories and significance to salmon populations are as follows:

Category	Mean Annual pH	Status of Salmon Populations
1	<4.7	No natural reproduction; run extinct
2	4.7-5.0	Population severely threatened; juvenile mortalities likely
3	5.1-5.4	Population threatened; episodic effects possible
4	>5.4	No immediate acidification threat.

Applying these categories to the weighted mean pH's for the insular Newfoundland study rivers it is apparent that all of the systems fit into the last two categories; that is none had a mean annual pH of less than 5.0. This would indicate that the study rivers have not experienced significant perturbation of resident salmon populations. However, five of the study rivers did demonstrate a weighted mean pH of less than 5.40, suggesting salmon populations on these systems are potentially threatened by continuing freshwater acidification. These rivers include the Cloud River (pH of 5.08) on the Northern Peninsula and D'Espoir Brook (pH of 5.14), Dolland Brook (pH of 5.20), Grey River (pH of 5.09) and White Bear River (pH of 5.30) on the south coast. Watt found thriving salmon runs in Nova Scotian rivers at these pH levels; however, he cautioned that other portions of these river systems may be experiencing acid stress (i.e. headwaters) and sublethal effects could not be ruled out. Good salmon runs are still evident on most major south coast rivers including Dolland Brook, Grey River, White Bear River as indicated by existing angling data (unpubl. data). In fact, south coast rivers in 1984 yielded the highest angling catch in many years. In addition, an electrofishing survey conducted in the summer of 1983 in the headwaters of the Grey and White Bear rivers indicated no apparent recruitment problems as juvenile salmon of 0^+, 1^+ and 2^+ were sampled (unpub. data). Available biological indicators suggest no major problems with salmon populations on the south coast at present.

As a consequence of this study and large scale lake inventories (Scruton 1983; and unpub. data) monitoring efforts have been focussed on the south coast, as the region with the greatest potential for impact from acidification. Some 20 rivers have been opportunistically monitored since 1982. Sampling frequency does not permit calculation of annual means; however, pH data does suggest that an additional 6 to 8 rivers could be classified in Watt's third category (pH 5.1 to 5.4) as having potentially threatened salmon populations. These rivers include Grand Bay River, Grandy's Brook (W), Rose Blanche River, King's Harbour Brook, and also possibly Isle aux Morts River and Grandy Brook (E) in the southwest (west of 57°30' longitude). Bottom Brook and Morgan Brook near the Dolland Brook area, and many smaller watersheds in this general region with small self sustaining salmon populations, may similarly be considered of concern.

The acidity of Cloud River would suggest that other rivers on the Northern Peninsula that drain the large granite and gneitic batholyth of the Long Range Mountains, may be demonstrating similar low pH levels. While a monitoring program has not been mounted on the Northern Peninsula there is a concern that major salmon producing rivers such as the Coney Arm River and Main River may be

susceptible to acidification effects. Samples collected on the Soufflet's River and Cat Arm River in July and September 1981, an expected period of high pH in the hydrological cycle, yielded relatively low pH values (5.47 to 5.60 for Soufflet's River, 4.87 to 5.21 for Cat Arm River), confirming the high acidity of other Northern Peninsula rivers.

In summary, a number of study rivers categorized according to Watt (1981) appear to be potentially threatened by continuing acidification, and monitoring efforts indicate the geographical scope of threatened rivers is broader than this limited study of 22 systems would suggest. Episodes of low pH are evident in both the fall and spring and pH minima on several rivers are in the range that have been demonstrated to have some potential impact on salmon recruitment. Spring pH minima generally occur at such a time as to coincide with the occurrence of newly hatched alevins and presmolts. The potential threat to the early life stages of salmonids is difficult to evaluate owing to the inability to establish exposure limits (extent and duration of pH depressions and levels of toxic aluminum). Additionally, most salmonid spawning and rearing habitat is associated with low order streams that are acknowledged to have greater susceptability to acidificiation than the mainstem. Samples collected in the mainstem (near the mouth) help to chemically define each major river system but do not categorize the acid sensitivity of all habitat(s) in the drainage system.

CONCLUSIONS

It is important to note that many of the conclusions made with the study rivers are largely based on the variability in water chemistry observed over the 13 month study period. There are indications that May '81 to May '82 was not representative of a typical year and that runoff was considerably higher than normal, particularly in the fall of 1981. Long term data records for some Newfoundland rivers (as discussed in Thompson and Bennett 1981) demonstrate how variable water chemistry can be from month to month and year to year, and a measure at this variability is probably attributable to changeable deposition patterns in the region.

The conclusion of this study, similar to those of other inventory efforts in insular Newfoundland, namely that chronic acidification is not a wide spread problem in major drainage systems on the island. Sampling efforts in connection with this study, however, do not adequately reflect the acidification process in the headwaters. Temporal evaluation suggests that episodic acidification may be the major concern, at present, in Newfoundland rivers.

Most of the study rivers are considered very sensitive to potential acidification on the basis of several criteria evaluated. Deficits in alkalinity are apparent on all rivers, reflecting consumption of bicarbonate in response to acid loadings, but no systems demonstrated total alkalinity depletion (exhaustion) on an annual basis. Six rivers (and one site on the Conne River) demonstrated an annual pH of less than 5.5 and these systems are being monitored for continued trends in relation to acidification or recovery from conditions experienced in 1981-82. Sulphate values are consistant with

other inventory data bases and are generally lower than in other Eastern Canadian localities experiencing higher acid loadings.

The influence of the marine environment on chemistry is apparent in the order of cationic dominance, with sodium being dominant on 20 rivers. Considering non-marine concentrations only, the pattern of cationic dominance is typically Ca > Na or Mg > K. Similarly chloride is the dominant anion on 22 rivers and the anionic order is typically $Cl > SO_4^{-2} > HCO_3^-$. Considering non-marine anions, sulphate is dominant to bicarbonate on 20 systems. Determination of organic anions ($COOH^-$) suggest that organics are a major anionic constituent in the chemistry of most rivers.

Temporal variability in most water quality parameters followed the patterns demonstrated by many other researchers. Base cations (Ca^{+2} and Mg^{+2}) varied inversely with discharge on most rivers reflecting a dilution effect of baseflow by precipitation and/or runoff. Sodium also varied inversely with discharge, but not on as many rivers as the base cations, reflecting both geological and precipitation sources for the ion. Both pH and alkalinity were inversely correlated to discharge indicating dilution of bicarbonate of terrestrial origin and H^+ inputs from natural and anthropogenic sources during peaks in the hydrological cycle.

Sulphate was positively correlated to discharge reflecting the importance of precipitation as the major source for this ion. Water colour, as a correlate of organic content, also varied positively with discharge, suggesting the flushing of organic deposits during high runoff periods. Annual peaks in colour values were mostly evident in the fall while highest sulphate values were evident in both the summer and fall of 1981.

Depressions in pH and alkalinity depletion were evident on all rivers, and two such periods were evident on most rivers in relation to fall and spring peaks in the hydrological cycle. Fall minima were experienced on several rivers, reflecting the abnormally high runoff in the fall of 1981 with concurrent large H^+ loadings from precipitation and terrestrial sources. A more expected pattern of spring minima in relation to snowmelt was evident on most rivers, particularly south coast systems. Minimum values for pH/alkalinity on south coast rivers may be a reflection of absolute lows as samples were collected within one or two days of peak discharge. On other rivers (east coast systems for example) samples were collected in the spring, 5 to 10 days or more prior to peak discharge, and further depression of pH and alkalinity may have occurred. Spring minima on most rivers in 1982 were evident in the month of April. Northern Penninsula rivers experience later spring minima, frequently in late May, as a result of delayed snowmelt due to considerations of topography and latitude.

Spring pH depressions on several rivers were of sufficient magnitude to potentially affect salmon recruitment. Conditions on the mainstem do not adequately describe the conditions in the spawning and rearing habitats which are often associated with the headwater streams. Elevation of aluminum in relation to pH decline and increase in discharge was not apparent on most rivers although greater sampling frequency would be required to adequately characterize these relationships. The association of aluminum with colour

values suggests much of the available aluminum is organically complexed and could be considered relatively non-toxic to resident fish. More study is needed to determine speciation of aluminum during episodes to evaluate whether aluminum need be considered as a toxic agent in Newfoundland freshwaters.

A comparison of the occurrance of spring peaks in the hydrological cycle and associated pH depressions with available information on the temporal development of salmonid eggs, alevins, and fry suggests maximum acidity on most rivers occurs in relation to the presence of alevins in the redd environment. Fry emergence (considered to be the most acid sensitive early life stage of salmon) likely occur in rivers after the spring hydrological peak and when pH is recovering from annual (or spring) lows. Salmon smolts or presmolts are also likely exposed to conditions of maximum acidity.

RECOMMENDATIONS

The results of this study have pointed several areas where additional research is needed to more clearly understand the process of acidification in Newfoundland rivers and the possible implications for resident fish. These research areas include:

- more frequent sampling during periods of high discharge/low pH to accurately describe the magnitude and duration of episodic acidification

- sampling should be conducted in the headwaters as well as the mainstem to determine in system variability in sensitivity to, and effects from, anthropogenic acidification. This may determine the adequacy of mainstem sampling in describing and monitoring the acidification process and may help more clearly define the area of potential impacts

- more frequent sampling for aluminum availability during episodes of low pH/high runoff with concurrent determination of component aluminum species

- the need to consider and include, on a routine basis, a quantitative measure of organic contributions to freshwater chemistry.

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Table 1. Analytical methods and detection limits for laboratory measured parameters.

Parameter	Analytical Procedure	Limit of Detection (mg/L)
Conductivity	Wheatstone Bridge Conductivity Meter	0.5
Colour	Visual Comparison using Heilige Aquatester	5.0
pH	Combination Glass & Reference Electrode, Fisher Accumet pH Meter	0.01
Turbidity	Nephelometric Method HF Turbidimeter	0.10
Total Dissolved Solids	Gravimetric Method	0.10
Sodium	Atomic Absorption (flame) on Varian AA	0.1
Potassium	Atomic Absorption (flame) on Varian AA	0.02
Calcium	Atomic Absorption (flame) on Varian AA	0.01
Magnesium	Atomic Absorption (flame) on Varian AA	0.02
Alkalinity	Technicon Auto Analyzer Colormetric Bromophenol Blue	0.1
Gran Alkalinity	Potentiometric Titration Canlab Repipet and Metrohm pH Meter	0.01
Sulphate	Technicon Auto Analyzer Colormetric Methylthymol Blue	1.0
Chloride	Technicon Auto Analyzer Colormetric Ferriccyanide/Thiocyanate	0.2

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Table 1. (Cont'd.)

Parameter	Analytical Procedure	Limit of Detection (mg/L)
Phosphate total as P	Technicon Auto Analyzer Molybate Ascorbic Colormetric-Acid	0.002
Nitrogen total as N	Technicon Auto Analyzer Colormetric	0.01
Dissolved Organic Carbon	Oxidation to CO_2 and Colorimetric Determination	1.0
Aluminum	Atomic Absorption (flameless) on Varian AA	0.05
Zinc	Atomic Absorption (flameless) on Varian AA	0.0011
Nickel	Atomic Absorption (flameless) on Varian AA	0.0012
Copper	Atomic Absorption (flameless) on Varian AA	0.009
Lead	Atomic Absorption (flameless) on Varian AA	0.0035
Cadmium	Atomic Absorption (flameless) on Varian AA	0.0005
Iron	Atomic Absorption (flame) on Varian AA	0.03
Manganese	Atomic Absorption (flame) on Varian AA	0.014

Table 2. Summary of volume weighted means (VWM) and ranges for physical and chemical parameters measured in the study rivers. Note: Sample number (N) is the same for all parameters as it is for pH (lab) except where noted. All values are μeq L^{-} except where otherwise specified.

	Northwest Brook 0401790			Cloud River 0401850			Badger River 0707791		
	N	V.W.M.	Range	N	V.W.M.	Range	N	V.W.M.	Range
pH (lab)	10	5.79	5.30-6.99	11	5.08	4.66-5.84	13	6.11	5.82-6.78
Alklinity (field)		54	35-135		10	-2 to 41		49	24-131
Conductivity (μScm^{-1})		22	15-40		23	18-48		14	10-21
TDS (mgL^{-1})		36.5	27-53		27.1	13-42		27.9	12-40
Hardness		128	102-204		67	43-105		142	127-188
Bicarbonate		65	43-165		14	0-50		60	29-160
Calcium		76	56-118		37	19-60		91	81-107
Magnesium		50	36-90		29	18-49		37	33-42
Sodium		89	68-131		77	60-114		81	64-91
Potassium		6	2-14		4	2-8		7	6-7
Cloride		117	96-183		98	68-133		89	68-152
Sulphate		71	38-104		63	35-104		47	40-83
Turbidity (J.T.U)		0.6	0.3-0.9		0.6	0.3-0.4		0.5	0.3-1.0
Colour (T.C.U)		91	10-150		55	40-100		55	40-65
Ex. Sulphate		55	14-90		49	17-92		35	18-74
Ex. Calcium		73	54-116		35	17-56		90	79-105
Ex. Magnesium		42	29-81		22	13-41		31	27-37
Ex. Sodium		24	12-48		22	12-40		32	5-42
Ex. Potassium		4	0-12		2	0-6		5	5-13
D.O.C. (mgL^{-1})	(2)	8.5	7.0-10.0	(2)	4.5	4.0-5.0	3)	7.7	6.0-9.0
Aluminum (μgL^{-1})	(3)	179	166-281	(3)	55	51-106	4)	81	56-152

Table 2. (Cont'd.)

	Noel Paul's Brook 0707794			Gander River 0908160			Ragged Harbour River 0908820		
	N	V.W.M.	Range	N	V.W.M.	Range	N	V.W.M.	Range
pH (lab)	12	6.27	5.99-6.97	12	6.07	5.75-6.71	12	5.57	5.05-7.21
Alkalinity (field)		64	36-126		34	22-68		19	1.60
Conductivity (μScm^{-1})		17	9-22		14	10-34		18	10-42
TDS (mgL^{-1})		20.4	3-53		22.6	9-65		36-4	18-42
Hardness		134	105-201		127	108-134		141	107-240
Bicarbonate		78	43-154		42	27-83		23	1-195
Calcium		92	70-138		72	57-77		64	48-112
Magnesium		42	35-63		55	49-61		71	58-128
Sodium		59	53-67		89	66-117		161	123-198
Potassium		4	2-7		7	6-11		6	5-14
Chloride		57	37-68		98	73-124		208	158-265
Sulphate		49	19-83		65	42-104		57	42-83
Turbidity (J.T.U.)		0.6	0.2-2.8		0.6	0.3-1.2		0.7	0.4-1.3
Colour (T.C.U.)		44	30-70		57	40-70		69	30-80
Ex. Sulphate		42	10-78		51	30-94		28	90-70
Ex. Calcium		91	69-137		70	55-76		60	45-108
Ex. Magnesium		38	31-60		48	43-53		63	47-117
Ex. Sodium		27	19-33		34	19-49		45	30-109
Ex. Potassium		2	1-5		5	4-8		2	1-9
D.O.C. (mgL^{-1})	(3)	8.0	7.0-9.0	(3)	8.3	7.0-9.0	(3)	9.7	8.0-11.0
Aluminum (μgL^{-1})	(4)	43	27-75	(3)	40	24-101	(4)	43	24-130

Table 2. (Cont'd.)

	Indian Bay Brook 1109490			Gambo River 1109780			Terra Nova River 1110221		
	N	V.W.M.	Range	N	V.W.M.	Range	N	V.W.M.	Range
pH (lab)	13	5.75	4.66-6.70	13	5.49	4.85-6.43	13	5.64	4.80-6.35
Alkalinity (field)		24	-0.3 to 61		21	5-76		19	-4 to 57
Conductivity (μScm^{-1})		16	10-42		12	10-30		13	10-34
TDS (mgL^{-1})		28.8	7-52		29-0	15-60		24.4	13-50
Hardness		118	96-166		105	37-127		92	72-111
Bicarbonate		30	0-74		26	6-93		23	0-70
Calcium		63	49-90		74	58-96		58	44-71
Magnesium		51	29-76		42	37-48		35	28-40
Sodium		118	87-157		92	72-141		75	64-144
Potassium		6	5-14		11	7-16		7	5-11
Chloride		114	102-243		102	82-130		88	68-166
Sulphate		51	35-83		60	10-104		56	31-104
Turbidity (J.T.U.)		0.6	0.3-1.7		0.7	0.4-1.2		0.6	0.4-1.0
Colour (T.C.U.)		50	25-120		78	60-100		64	50-90
Ex. Sulphate		31	13-69		48	15-92		44	16-93
Ex. Calcium		60	47-85		72	57-94		56	43-68
Ex. Magnesium		42	20-60		35	31-37		29	23-35
Ex. Sodium		38	0-93		35	19-70		27	17-52
Ex. Potassium		3	0-11		9	5-14		5	2-9
D.O.C. (mgL^{-1})	(3)	8.0	6.0-10.0	(3)	11.3	9.0-13.0	(3)	10.3	7.0-12.0
Aluminum (μgL^{-1})	(4)	57	43-101	(4)	75	21-202	(4)	75	24-101

Table 2. (Cont'd.)

	Southwest River 1210930			Biscay Bay (Back) Brook 2700220			Colinet River 2810920		
	N	V.W.M.	Range	N	V.W.M.	Range	N	V.W.M.	Range
pH (lab)	13	5.72	5.13-6.89	13	5.75	4.78-7.06	13	6.08	5.69-7.06
Alkalinity (field)		28	-8.3 to 96		23	-3.3 to 73		51	-0.2 to 98
Conduct ($\mu S\ cm^{-1}$)		14	10 to 45		22	12-35		20	11-28
TDS (mgL^{-1})		32.1	10-79		28.2	17-42		34.5	15-44
Hardness		107	91-134		112	83-212		150	123-202
Bicarbonate		36	0-117		28	0-89		62	0-120
Calcium		71	49-97		51	37-91		86	71-115
Magnesium		36	26-52		61	45-122		64	52-87
Sodium		118	94-188	(12)	199	149-335		188	143-281
Potassium		4	3-8		6	4-14		7	6-13
Chloride		113	96-161		220	138-488		207	152-330
Sulphate		81	33-125		68	42-104		74	42-125
Turbidity (J.T.U.)		0.8	0.4-1.0		0.9	0.3-7.2		1.2	0.3-7.8
Colour (T.C.U.)		81	45-150		44	5-75		62	25-100
Ex. Sulphate		65	11-112		38	1-85		45	5-100
Ex. Calcium		69	47-95		47	34-81		82	68-108
Ex. Magnesium		29	19-45		46	35-89		50	40-65
Ex. Sodium		55	36-113	(12)	79	61-96		73	55-104
Ex. Potassium		2	1-5		2	1-6		3	1-8
D.O.C. (mgL^{-1})	(3)	7.7	6.0-9.0	(3)	3.0	2.0-5.0	(3)	7.3	6.0-10.0
Aluminum (μgL^{-1})	(4)	43	25-152	(4)	116	31-55	(4)	41	29-75.

Table 2. (Cont'd.)

	Rocky River 2801930			Pipers Hole River 3004160			Long Harbour River 3409780		
	N	V.W.M.	Range	N	V.W.M.	Range	N	V.W.M.	Range
pH (lab)	13	5.71	5.12-6.94	13	5.91	5.38-6.88	12	5.62	5.09-6.66
Alkalinity (field)		30	-0.4 to 113		31	-1.6 to 84		22	8.5 to 49
Conductivity (μScm^{-1})		21	10-33		12	10-33		16	9-30
TDS (mgL^{-1})		37.7	21-49		21.7	6-69		24.3	26-34
Hardness		14.7	116-229		98	72-136		72	52-135
Bicarbonate		37	0-138		38	0-102		27	10-60
Calcium		81	67-118		70	50-93		47	33-93
Magnesium		65	49-120		29	17-43		25	19-42
Sodium		190	140-316		88	67-131		88	69-156
Potassium		7	5-13		5	3-12		5	4-10
Chloride		225	141-440		100	73-166		100	73-175
Sulphate		83	42-146		63	29-125		50	21-83
Turbidity (J.T.U.)		0.7	0.3-1.2		0.7	0.4-0.9	(11)	0.8	0.4-1.2
Colour (T.C.U.)		89	15-150		56	30-70		47	30-70
Ex. Sulphate		52	0-121		49	16-113		36	8-73
Ex. Calcium		77	61-110		67	49-92		45	31-89
Ex. Magnesium		50	39-91		22	12-32		18	13-30
Ex. Sodium		65	51-94		32	7-69		33	14-59
Ex. Potassium		3	1-4		2	1-9		3	2-7
D.O.C. (mgL^{-1})	(3)	5.7	5.0-6.0	(3)	7.3	6.0-10.0	(3)	4.7	4.0-6.0
Aluminum (μgL^{-1})	(4)	47	29-75	(4)	36	20-152	(4)	45	35-88

Table 2. (Cont'd.)

	Baie du Nord River 3401790			Conne River "A" 3613351			Conne River "B" 3613352		
	N	V.W.M.	Range	N	V.W.M.	Range	N	V.W.M.	Range
pH (lab)	13	5.54	5.14-7.22	12	5.70	5.17-6.79	12	5.85	5.47-6.79
Alkalinity (field)		11	-2.6 to 29		32	10 to 99		39	25 to 93
Conductivity (μScm^{-1})		16	8-32		17	10-30		17	10-36
TDS (mgL^{-1})		26.0	14-41		18.6	19-43		29-7	17-43
Hardness		89	72-145		115	81-179		121	86-173
Bicarbonate		14	0-35		39	12-121		47	31-113
Calcium		54	43-88		78	52-117		80	57-114
Magnesium		35	29-57		37	27-62		40	29-58
Sodium		88	70-169		71	63-109		74	64-119
Potassium		3	4-11		6	4-12		6	4-12
Chloride		99	85-229		87	73-135		92	73-248
Sulphate		52	35-83		64	38-104		62	35-104
Turbidity (J.T.U.)		0.7	0.3-1.1	(11)	0.7	0.3-1.2		0.7	0.3-1.2
Colour (T.C.U.)		51	25-80		71	45-100		71	40-150
Ex. Sulphate		38	14-68		52	27-89		50	20-91
Ex. Calcium		52	42-83		76	50-115		78	55-111
Ex. Magnesium		28	23-42		31	22-53		34	24-49
Ex. Sodium		33	15-43		23	16-37		26	20-41
Ex. Potassium		3	3-8		4	3-10		4	2-9
D.O.C. (mgL^{-1})	(3)	7.0	6.0-8.0	(3)	9.0	8.0-10.0	(3)	8.7	7.0-10.0
Aluminum (μgL^{-1})	(4)	45	29-90	(4)	38	22-94	(4)	53	27-169

Table 2. (Cont'd.)

	Conne River "C" 3613353			Baie D'Espoir Brook 3614260			Dolland Brook 3615270		
	N	V.W.M.	Range	N	V.W.M.	Range	N	V.W.M.	Range
pH (lab)	12	5.46	5.03-6.59	11	5.14	4.62-6.12	13	5.20	4.89-6.32
Alkalinity (field)		22	5.8 to 179		11	-2.8 to 46		16	4.4 to 39
Conductivity (μScm^{-1})		16	9-30		16	8-30		15	7.3-30
TDS (mgL^{-1})		29.6	11-45		21.8	9-39		19.9	16-36
Hardness		102	77-176		64	38-106		66	47-107
Bicarbonate		27	7-218		14	0-56		20	5-48
Calcium		72	53-123		37	23-64		41	10-70
Magnesium		30	23-54		27	16-42		22	15-36
Sodium		75	62-130		75	58-117		75	61-136
Potassium		7	5-14		2	2-8		4	2-8
Chloride		92	79-169		87	68-158		86	73-175
Sulphate		63	42-104		55	27-104		43	33-83
Turbidity (J.T.U.)		0.7	0.3-1.2		0.6	0.3-0.9		0.7	0.4-0.8
Colour (T.C.U.)		74	55-100		51	30-80		50	30-100
Ex. Sulphate		51	29-85		43	18-93		31	18-72
Ex. Calcium		70	51-119		36	21-62		41	30-67
Ex. Magnesium		24	18-43		21	11-33		17	10-25
Ex. Sodium		23	15-40		27	20-37		27	13-39
Ex. Potassium		5	3-11		2	1-5		2	0-5
D.O.C. (mgL^{-1})	(3)	9.0	8.0-11.0	(3)	5.3	4.0-6.0	(3)	6.3	6.0-7.0
Aluminum (μgL^{-1})	(4)	35	28-56	(4)	49	36-112	(4)	46	36-101

Table 2. (Cont'd.)

	Grey River 3716620			White Bear River 3717440			La Poile River 3818800		
	N	V.W.M.	Range	N	V.W.M.	Range	N	V.W.M.	Range
pH (lab)	12	5.09	4.71-6.36	12	5.30	4.98-6.51	11	5.70	5.52-6.55
Alkalinity (field)		9	-2.4 to 63		20	13-90		12	-1.3 to 78
Conductivity (μScm^{-1})		13	90-30		20	9-50		19	12-40
TDS (mgL^{-1})		20.9	12-36		23.3	19-35		22.7	14-75
Hardness		59	32-135		69	34-144		105	51-214
Bicarbonate		13	0-77		24	16-110		16	0-95
Calcium		40	22-101		45	23-102		66	32-167
Magnesium		19	10-35		23	12-41		39	17-51
Sodium		64	49-124		69	46-147		119	57-378
Potassium		4	2-9		5	2-12		6	3-16
Chloride		70	51-141		72	45-119		133	56-186
Sulphate		46	29-104		45	29-83		56	21-83
Turbidity (J.T.U.)		1.0	0.1-1.6		0.7	0.3-0.9		0.6	0.2-0.8
Colour (T.C.U.)		52	30-80		55	35-80		31	5-50
Ex. Sulphate		37	22-96		35	23-73		38	11-68
Ex. Calcium		39	21-98		44	22-100		63	31-163
Ex. Magnesium		14	7-27		18	9-34		30	12-43
Ex. Sodium		25	15-50		29	17-89		45	19-275
Ex. Potassium		3	0-6		4	1-9		3	1-12
D.O.C. (mgL^{-1})	(3)	6.0	5.0-7.0	(3)	6.3	6.0-7.0	(2)	3.5	3.0-4.0
Aluminum (μgL^{-1})	(4)	50	44-91	(4)	60	54-101	(3)	40	31-101

Table 3. Comparison of marine contribution to the water chemistry of the study rivers sampled May '81 to May '82 and headwater lakes sampled August to September 1981 (Scruton 1983).

	Headwater lakes Insular Newfoundland (N = 109)			Salmon rivers Insular Newfoundland (N = 24)		
	Mean value (μeq)	Mean Non-Marine value (μeq)	% Marine Contribution	Mean value (μeq)	Mean Non-Marine value (μeq)	% Marine Contribution
Chloride	87.8	-	100	116.0	-	100
Sodium	82.3	32.9	60	100.9	36.6	64
Potassium	3.3	1.5	55	6.3	3.5	44
Sulphate	46.8	34.5	26	59.3	43.3	27
Magnesium	50.2	44.2	12	40.4	32.6	19
Calcium	102.5	101.6	<1	64.5	62.2	4

Table 4. Dissolved organic carbon (DOC) in mgL^{-1} and calculated organic anions[1] ($COOH^-$) in $\mu eq\ L^{-1}$ for the study rivers

River	March 1982 DOC	March 1982 $COOH^-$	April 1982 DOC	April 1982 $COOH^-$	May 1982 DOC	May 1982 $COOH^-$	Arithmetic means DOC	Arithmetic means $COOH^-$
Northwest Bk.	7.0	70	10.0	88	-	-	8.5	79
Cloud R.	4.0	36	5.0	42	-	-	4.5	39
Badger R.	8.0	71	9.0	81	6.0	54	7.7	69
Noel Paul's Bk.	8.0	76	9.0	86	7.0	64	8.0	75
Gander R.	9.0	83	9.0	82	7.0	63	8.3	76
Ragged Harbour R.	10.0	88	11.0	92	8.0	69	9.7	83
Indian Bay Bk.	8.0	78	10.0	87	6.0	58	8.0	74
Gambo R.	13.0	108	12.0	96	9.0	76	11.3	93
Terra Nova R.	12.0	100	12.0	100	7.0	56	10.3	85
Southwest Bk.	9.0	78	8.0	63	6.0	53	7.7	65
Biscay Bay (Back) Br.	2.0	16	5.0	39	2.0	18	3.0	24
Colinet R.	6.0	55	10.0	89	6.0	53	7.3	66
Rocky's R.	6.0	50	6.0	50	5.0	45	5.7	48
Pipers Hole R.	10.0	89	6.0	50	6.0	53	7.3	64
Long Harbour R.	4.0	37	4.0	31	6.0	-	4.7	34
Baie du Nord R.	8.0	71	7.0	58	6.0	-	7.0	65
Conne R. (A)	9.0	85	10.0	80	8.0	75	9.0	80
Conne R. (B)	10.0	94	9.0	77	7.0	-	8.7	86
Conne R. (C)	11.0	102	8.0	62	8.0	-	9.0	82
Baie D'Espoir Bk.	6.0	52	6.0	41	4.0	-	5.3	47
Dolland Bk.	6.0	52	6.0	45	7.0	-	6.3	49
Grey R.	5.0	46	6.0	42	7.0	-	6.0	44
White Bear R.	6.0	58	7.0	53	6.0	-	6.3	56
LaPoile R.	3.0	28	4.0	34	-	-	3.5	31

[1]Organic anions calculated after Oliver et. al.(1983)

Table 5. Aluminum data for the study rivers

RIVER	Total Aluminum ($\mu g\ L^{-1}$) Sample Month May 1981	March 1982	April 1982	May 1982	Arithmetic Mean	Weighted Mean
Northwest Bk.	170	164	278	-	204	177
Cloud R.	50	81	104	-	78	54
Badger R.	150	74	55	77	89	80
Noel Paul's Bk.	50	74	61	27	53	42
Gander R.	100	-	23	52	58	40
Ragged Harbour R.	50	129	23	62	66	42
Indian R.	100	60	42	60	66	57
Gambo R.	200	123	21	91	109	74
Terra Nova R.	100	97	23	62	70	75
Southwest Bk.	150	101	25	53	82	42
Biscay Bay (Back) Br.	50	55	31	41	44	38
Colinet R.	50	75	29	43	49	40
Rocky's R.	50	74	43	29	49	47
Pipers Hole R.	150	72	20	48	72	36
Long Harbour R.	50	87	34	46	54	44
Baie du Nord R.	50	89	29	61	58	41
Conne R. (A)	50	93	22	49	53	38
Conne R. (B)	50	167	27	52	74	52
Conne R. (C)	50	56	28	35	42	34
Baie D'Espoir Bk.	50	111	36	48	61	49
Dolland Bk.	100	58	36	54	62	46
Grey R.	50	90	43	70	63	49
White Bear R.	100	62	53	62	69	59
LaPoile R.	100	74	31	-	68	40

Table 6. Cation denudation rate (CDR), runoff, and sulphate loading for 8 guaged study rivers including comparison with data from Thompson (1982) and long term average runoff data.

Note: Runoff for the 13 month study period adjusted to 12 month (annual) average

RIVER	CDR (meq m^{-2} yr^{-1}) This study	(a)	Thompson (1982)	Runoff (myr^{-1}) This study	(b)	Long term average	(n)	Sulphate Load meq m^{-2} yr^{-1} This Study	(c)	Thompson (1982)	This Study
Gander R.	160	+65%	97	1.02	+20%	0.85	34	52	-10%	58	6.07
Ragged Harbour R.	150			0.88	+16%	0.76	6	25			5.57
Gambo R.	140			0.92	+15%	0.80	24	44			5.49
Terra Nova R.	123	+62%	76	1.05	+19%	0.88	28	46	-	46	5.64
Southwest Br.	157			1.01	+16%	0.87	16	66			5.72
Rocky R.	257	+93%	133	1.32	+ 6%	1.24	34	69	-32%	101	5.71
Pipers Hole R.	183	+81%	101	1.49	+45%	1.03	31	73	+14%	64	5.91
Baie du Nord R.	164			1.40	+28%	1.09	31	53			5.54

a = proportional difference between CDR of this study vs CDR of Thompson (1982)
b = proportional difference between annual runnoff during study period vs average for period of hydrological record.
n = number of years in the hydrological record (to 1983)
c = proportional difference between the sulphate loading during the study period and loadings used in CDR model development (Thompson 1982)

Table 7. Summary of pH data for the study rivers.

River	Region	Mean pH (volume weighted)	Minimum pH	Month of minima	Maximum pH	Month of maxima	Range
Northwest Bk.	NP	5.79	5.30	Dec. '81	6.99	July '81	1.69
Cloud R.	NP	5.08	4.66	Dec. '81	5.84	July '81	1.18
Badger R.	C	6.11	5.82	Mar. '81	6.78	Sept. '81	0.96
Noel Paul's Bk.	C	6.27	5.99	Nov. '81	6.97	May '81	0.98
Gander R.	E	6.07	5.75	Jan. '81	6.71	May '81	0.96
Ragged Harbour R.	E	5.57	5.05	Nov. '81	7.21	Sept. '81	2.16
Indian Bay Bk.	E	5.75	4.66	Nov. '81	6.70	Aug. '81	2.04
Gambo R.	E	5.49	4.85	Dec. '81	6.43	July '81	1.58
Terra Nova R.	E	5.64	4.80	Dec. '81	6.35	May '81	1.55
Southwest Bk.	E	5.72	5.13	Apr. '82	6.89	May '81	1.76
Biscay Bay Bk.	AP	5.75	4.78	Jan. '82	7.06	May '81	2.28
Colinet R.	AP	6.08	5.69	Apr. '82	7.06	May '81	1.37
Rocky R.	AP	5.71	5.12	Sept. '81	6.94	May '81	1.82
Pipers Hole R.	SC	5.91	5.38	Apr. '82	6.88	May '81	1.50
Long Harbour R.	SC	5.62	5.09	Apr. '82	6.66	June '81	1.57
Baie du Nord R.	SC	5.54	5.14	Sept. '81	6.22	July '81	1.08
Conne R. (A)	SC	5.70	5.17	Apr. '82	6.79	July '81	1.62
Conne R. (B)	SC	5.85	5.47	Apr. '82	6.79	July '81	1.32
Conne R. (C)	SC	5.46	5.03	Apr. '82	6.59	July '81	1.56
Baie D'Espoir Bk.	SC	5.14	4.62	Apr. '82	6.12	July '81	1.50
Dolland Bk.	SC	5.20	4.89	Apr. '82	6.32	May '81	1.43
Grey R.	SC	5.09	4.71	Apr. '82	6.36	May '81	1.65
White Bear R.	SC	5.30	4.98	Apr. '82	6.51	May '81	1.53
La Poile R.	SC	5.70	5.52	Apr. '82	6.55	Feb. '82	1.03
		5.08-6.27 $\bar{x}$ = 5.65	4.62-5.99 $\bar{x}$ = 5.15		5.84-7.21 $\bar{x}$ = 6.66		0.96-2.28 $\bar{x}$ = 1.51

* NP = Northern Peninsula
C = Central
E = Eastern
AP = Avalon Peninsula
SC = South Coast

Table 8. Comparison of pH data collected in 1981-1982 with historical data for 7 of the study rivers.

River system	May 1981-May 1982 Data						Historical Data[b]					
	n	$\bar{x}$pH	$\bar{x}$pH[a]	Min.	Max.	Range	Year	n	$\bar{x}$pH	Min.	Max.	Range
Gander River	12	6.21	6.07	5.75	6.71	0.96	1972	9	6.01	5.70	6.40	0.70
							1973	10	5.95	4.70	7.20	2.50
							1974	9	6.12	5.80	6.60	0.80
							1975	8	5.25	5.50	7.00	1.50
							1976	6	6.23	5.80	7.00	1.30
							1977	13	6.39	5.60	7.20	1.60
							1978	12	6.38	5.90	7.10	1.20
								68	6.20	4.70	7.20	2.50
Ragged Harbour River	12	6.01	5.57	5.05	7.21	2.16	1978	8	5.91	5.35	6.25	0.90
							1979	11	6.22	5.30	7.50	2.20
							(77-80)	29	6.04	5.30	7.50	2.20
Gambo River[c]	13	5.75	5.49	4.85	6.43	1.58	1978	8	5.68	4.45	6.10	1.65
							1979	11	5.91	5.13	6.52	1.39
							(77-80)	28	5.84	4.45	6.52	2.07
Terra Nova River	13	5.72	5.64	4.80	6.35	1.55	1970	12	5.53	4.50	5.80	1.30
							1971	10	5.70	5.30	6.00	1.70
							1972	11	5.83	5.00	6.20	1.20
							1973	10	5.73	5.00	6.50	1.50
							1974	9	5.84	5.20	6.40	1.20
							1975	10	6.20	5.30	7.30	2.00
							1976	11	5.97	5.30	6.80	1.50
							1977	11	5.83	4.70	6.30	1.60
							1978	10	5.93	5.50	6.50	1.00
								109	5.88	4.50	7.30	2.80
Southwest Brook	13	6.00	5.72	5.13	6.89	1.76	1977	6	5.66	5.12	6.12	1.00
							1978	8	5.94	5.30	6.86	1.56
							1979	12	5.91	4.95	7.05	2.10
							1980	10	5.87	5.48	6.32	0.84
							(77-80)	32	5.90	4.95	7.05	2.10

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Table 8. (Cont'd.)

River system	May 1981-May 1982 Data						Historical Data[b]					
	n	$\bar{x}$pH	$\bar{x}$pH[a]	Min.	Max.	Range	Year	n	$\bar{x}$pH	Min.	Max.	Range
Rocky River	13	5.92	5.71	5.12	6.94	1.82	1972	12	5.89	4.20	6.70	2.50
							1973	11	5.75	4.90	6.50	1.60
							1974	11	6.08	5.30	6.60	1.30
							1975	10	6.39	5.80	7.30	1.50
							1976	12	6.46	5.70	7.40	1.70
							1977	10	6.33	4.90	7.00	2.10
							1978	10	6.27	6.00	6.80	0.80
							1979	6	6.50	6.10	6.80	0.70
							1980	10	6.22	5.70	6.50	0.80
							1981	12	6.20	5.60	6.50	0.90
							1982	11	6.29	5.70	6.70	1.00
							1983	11	6.10	5.50	6.60	1.10
							1984	14	6.31	5.50	6.60	1.10
							(72-84)	146	6.20	4.20	7.40	3.20
Pipers Hole River	13	6.18	5.91	5.38	6.88	1.50	1972	11	5.94	4.70	7.00	2.30
							1973	12	6.12	5.80	7.10	1.30
							1974	10	6.01	4.80	7.10	2.30
							1975	10	6.53	5.80	7.30	1.50
							1976	12	6.48	5.60	7.30	1.70
							1977	12	6.53	6.00	7.30	1.30
							1978	10	6.64	6.10	6.90	0.80
							1979	6	6.63	6.20	7.10	0.90
							1980	10	6.41	6.20	6.60	0.40
							1981	20	6.38	6.00	6.70	0.70
							1982	16	6.42	5.40	6.80	1.40
							1983	11	6.14	5.70	6.60	0.90
							1984	9	6.40	6.10	6.80	0.70
							(72-84)	154	6.34	4.70	7.30	2.60

[a]Is volume weighted mean pH.

[b]Historical data as provided by Environment Canada, Water Quality Branch, Moncton, N.B.

[c]Data is for Middle Brook (major tributary of Gambo River).

Table 9. Correlation coefficients for significant regressions ($P \leq 0.25$) of log discharge vs the logarithm of selected physical and chemical parameters.

River System	N	Parameter				
		pH(lab)	Alkalinity (field)	Conductivity	T.D.S.	Hardness
Northwest Bk.	10	-0.53	-0.79[a]	-0.54	-	-0.79[a]
Cloud R.	11	-0.65[a]	-0.45	-	-	-0.46
Badger R.	13	-	-0.37	-	-	-
Noel Paul's Bk.	12	-0.37	-0.63[a]	-	-0.65[a]	-
Gander R.	12	-0.43	-	-	-0.44	0.66[a]
Ragged Harbour R.	12	-0.83[a]	-0.78[a]	-0.56	-0.52	-0.65[a]
Indian Bay Bk.	13	-0.58[a]	-0.47	-	-0.35	0.35
Gambo R.	13	-0.76[a]	-0.71[a]	-0.54	-0.42	-
Terra Nova R.	13	-	-	-	-	-
Southwest R.	12	-0.52	-0.41	-0.46	-	-
Biscay Bay (Back) Bk.	13	-	-	-0.57[a]	-	-0.54
Colinet R.	13	-	-0.49	-	-	-0.37
Rocky R.	13	-0.48	-0.86[a]	-	-	-0.52
Pipers Hole R.	13	-0.55	-0.54	-0.60[a]	-	-
Long Harbour R.	13	-0.80[a]	-0.74[a]	-0.37	-	-0.57[a]
Baie du Nord R.	13	-0.69[a]	-0.42	-0.41	-	-
Conne R. (A)	12	-0.87[a]	-0.83[a]	-0.57	-0.41	-0.71[a]
Conne R. (B)	12	-0.89[a]	-0.87[a]	-0.62[a]	-	-0.51
Conne R. (C)	11	-0.95[a]	-0.85[a]	-0.58	-	-0.61[a]
Baie d'Espoir Bk.	13	-0.92[a]	-0.79[a]	-	-	-0.45
Dolland Bk.	12	-0.61[a]	-0.44	-0.38	-	-0.55
Grey R.	12	-0.72[a]	-0.69[a]	-0.62[a]	-0.38	-0.66[a]
White Bear R.	12	-0.70	-0.73[a]	-	-0.51	-0.63[a]
La Poile R.	11	-0.75[a]	-0.76	-0.44	-	-

[a]Significant at $P \leq 0.05$.

Table 9. (Cont'd.)

River System	Calcium	Magnesium	Sodium	Potassium	Chloride
Northwest Bk.	-0.72	-0.82	-0.50	-	-
Cloud R.	-0.44	-0.51	-0.46	-	-
Badger	-	-0.53	-	-	-
Noel Paul's Bk.	-	-	-	-0.44	-
Gander R.	0.48	0.58[a]	-	-	0.40
Ragged Harbour R.	-0.52	-0.68[a]	-	-0.39	-
Indian Bay Bk.	-	-	-	-	-
Gambo R.	-	-	-	0.36	-
Terra Nova R.	-	-	-	-0.43	-
Southwest R.	-	-	-0.50	-0.63[a]	-0.81[a]
Biscay Bay (Back) Bk.	-0.61[a]	-0.45	-	-	-
Colinet R.	-	-0.38	-0.52	-	-0.45
Rocky R.	-0.50	-0.50	-0.57[a]	-	-0.45
Pipers Hole R.	-	-	-0.38	-0.47	-
Long Harbour R.	-0.59[a]	-0.41	-0.45	-0.44	-
Baie du Nord R.	-	-	-	-0.50	-0.42
Conne R. (A)	-0.65[a]	-0.70[a]	-0.58[a]	-0.43	-0.41
Conne R. (B)	-0.48	-0.48	-0.49	-0.46	-
Conne R. (C)	-0.55	-0.59	-0.45	-0.57	-0.39
Baie d'Espoir Bk.	-0.47	-	-0.38	-0.50	-
Dolland Bk.	-	-0.46	-0.48	-	-0.50
Grey R.	-0.70[a]	-0.58[a]	-0.64[a]	-	-0.56
White Bay R.	-0.67[a]	-0.55	-0.64[a]	-	-0.58[a]
La Poile R.	-0.40	-	-	-0.39	-

[a]Significant at $P \leq 0.05$.

Table 9. (Cont'd.)

River System	Bicarbonate	Sulphate	Excess Sulphate	Colour	Turbidity
Northwest Bk.	-0.78[a]	0.49	0.47	-	-
Cloud R.	-	0.60	0.58	-	-
Badger R.	-0.39	0.41	-	0.47	-
Noel Paul's Bk.	-0.53	-	-	0.41	-
Gander R.	-	-	-	0.57	0.44
Ragged Harbour R.	-0.77[a]	-	-	0.77[a]	-
Indian Bay Bk.	-	-	-	0.46	0.45
Gambo R.	-0.71[a]	-	-	0.42	
Terra Nova R.	-	-	-	-	-
Southwest R.	-	0.62[a]	0.67[a]	0.70[a]	0.74[a]
Biscay Bay (Back) Bk.	-	0.45	-	0.58[a]	-
Colinet R.	-	0.74	0.79	0.66[a]	-
Rocky R.	-	0.67[a]	0.46	0.51[a]	-
Pipers Hole R.	-0.40	-	-	0.64[a]	0.41
Long Harbour R.	-0.74[a]	0.39	0.45	0.45	0.58
Baie du Nord R.	-	-	-	-	-
Conne R. (A)	-0.82[a]	-	-	-	-
Conne R. (B)	-0.87[a]	-	-	-	-
Conne R. (C)	-0.85[a]	-	-	-	-
Baie d'Espoir Bk.	-0.47	-	-	-	-
Dolland Bk.	-	-	-	-	-
Grey R.	-0.69[a]	-	-	-	0.38
White Bear R.	-0.73[a]	-	-	-	0.55
La Poile R.	-	-	-	0.50	0.60

[a]Significant at $P \leq 0.05$.

Table 9. (Cont'd.)

River System	Ex. Calcium	Ex. Mag.	Ex. Sodium	Ex. Pot.	Aluminum
Northwest Bk.	-0.72[a]	-0.83[a]	-0.52	-	-
Cloud R.	-0.45	-0.54	-0.46	-	-
Badger R.	-	-0.40	-	-0.64[a]	-
Noel Paul's Bk.	-	-	-	-0.59[a]	-0.79 (n = 4)
Gander R.	0.46	0.53	-	-0.50	-0.99 (n = 3)
Ragged Harbour R.	-0.53	-0.75[a]	-0.38	-0.62[a]	-
Indian Bay Bk.	-	-	-	-	
Gambo R.	-	-	-	0.36	-0.89 (n = 4)
Terra Nova R.	-	-	-	-	-
Southwest R.	-	-	-	-0.36	-0.87 (n = 4)
Biscay Bay (Back) Bk.	-0.64[a]	-0.50	-	-	-
Colinet R.	-	-	-0.49	-	-0.82 (n = 4)
Rocky R.	-0.45	-0.50	-0.74[a]	-0.40	-
Pipers Hole R.	-	-	-0.56	-0.58	-0.90 (n = 4)
Long Harbour R.	-0.59	-0.42	-0.48	-0.44	-
Baie du Nord R.	-	-	-	-0.46	-
Conne R. (A)	-0.65[a]	-0.72[a]	-0.60[a]	-0.39	-
Conne R. (B)	-0.47	-0.47	-0.46	-0.48	-
Conne R. (C)	-0.55	-0.63[a]	-0.45	-0.58	-0.83 (n = 4)
Baie d'Espoir Bk.	-0.47	-	-0.35	-0.54	-
Dolland Bk.	-0.59	-0.42	-	-	-
Grey R.	-0.70[a]	-0.56	-0.58	-	-0.84 (n = 4)
White Bear R.	-0.67[a]	-0.54	-0.55	-	-
La Poile R.	-0.41	-	-	-0.46	-

[a]Significant at $P \leq 0.05$.

Table 10. The proportion (%) of bedrock with different capacities to buffer acid deposition in each study river watershed

River	Buffering capacity of bedrock			
	Low to None	Medium to Low	Medium to High	Infinite
Northwest Bk.	83			17
Cloud R.	100			
Badger R.	26	74		
Noel Paul's Bk.	19	81		
Gander R.	12	88		
Ragged Harbour R.	14	86		
Indian Bay Bk.	48	52		
Gambo R.	46	54		
Terra Nova R.	31	69		
Southwest Bk.	8	92		
Biscay Bay (Back) Bk.		100		
Colinet R.		100		
Rocky's R.		100		
Pipers Hole R.	32	68		
Long Harbour R.	97	3		
Baie du Nord R.	60	40		
Conne R. (A)	11	89		
Conne R. (B)		100		
Conne R. (C)		100		
Baie D'Espoir Bk.	78	22		
Dolland Bk.	92	8		
Grey R.	73	27		
White Bear R.	83	17		
LaPoile R.	13	87		

Table 11. Listing of parameters used to define sensitivity to acid precipitation.

River	Alkalinity ($\mu eq\ L^{-1}$)	Calcium ($\mu eq\ L^{-1}$)	Conductivity (μScm^{-1})	CSI[a]	pH
Northwest Br.	54	76	22	-3.83	5.79
Cloud R.	10	37	23	-6.52	5.08
Badger R.	49	91	14	-4.56	6.11
Noel Paul's Bk.	64	92	17	-4.19	6.27
Gander R.	34	72	14	-4.76	6.07
Ragged Harbour R.	19	64	18	-5.58	5.57
Indian Bay Br.	24	63	16	-5.28	5.75
Gambo R.	21	74	12	-5.54	5.49
Terra Nova R.	19	58	13	-5.55 (-4.9)	5.64
Southwest Bk.	28	71	14	-5.18	5.72
Biscay Bay(Back) Br.	23	51	22	-5.41	5.75
Colinet R.	51	86	20	-4.51	6.08
Rocky's R.	30	81	21	-5.12 (-4.3)	5.71
Pipers Hole R.	31	70	12	-4.98 (-4.2)	5.91
Long Harbour R.	22	47	16	-5.42	5.62
Baie du Nord R.	11	54	16	-5.88	5.54
Conne R. (A)	32	78	17	-5.29	5.70
Conne R. (B)	39	80	17	-4.89	5.85
Conne R. (C)	22	72	16	-5.57	5.46
Baie D'Espoir Bk.	11	37	16	-6.46	5.14
Dolland Bk.	16	41	15	-6.20	5.20
Grey R.	9	40	13	-6.50	5.09
White Bear R.	20	45	20	-5.99	5.30
LaPoile R.	12	66	19	-5.59	5.70

[a]Calcite Saturation Index (CSI) values in ( ) are long term averages from Clair and Whitfield (1983)

Table 12. Sensitivity of the study rivers to acidification in relation to various aquatic criteria

1. Alkalinity[a] (μeqL^{-1})	Sensitivity to Acidification	No of Rivers (Sites)	(%)
less than 0	Acidified	-	-
0- 40	Extremely sensitive	18(20)	82%
40-200	Highly sensitive	4(4)	18%
200-500	Moderately sensitive	-	-
greater than 500	Not sensitive	-	-
2. Calcium[b] (μeqL^{-1})			
0-200	Highly sensitive	22(24)	100%
200-400	Moderately sensitive	-	-
greater than 400	Least sensitive	-	-
3. Conductivity[c] (μScm^{-1})			
0-35	Highly sensitive	22(24)	100%
22-78	Moderately sensitive	-	-
Greater than 60	Least sensitive	-	-
4. Calcite Saturation Index (CSI)			
less than -3	Deleterious effects possible	22(24)	100%
-2 to -3	Danger	-	-
-1 to -2	Moderate sensitivity	-	-
greater than -1	Low sensitivity	-	-

[a]Ontario Ministry of The Environment (1981).

[b]Harvey et al. (1981).

[c]Gorham (1978).

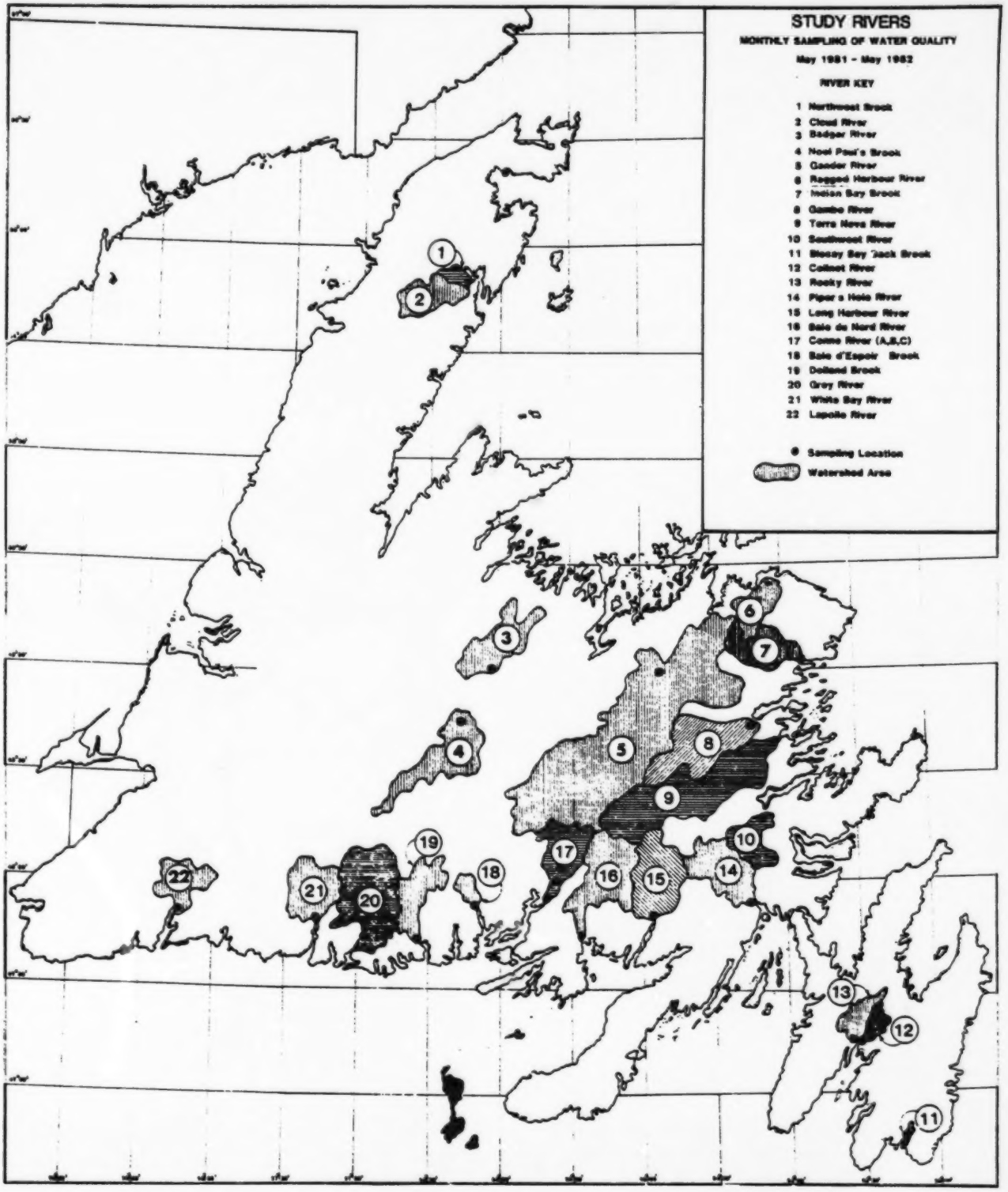

Fig. 1. Location of 22 study rivers including watersned boundaries and location of sampling sites.

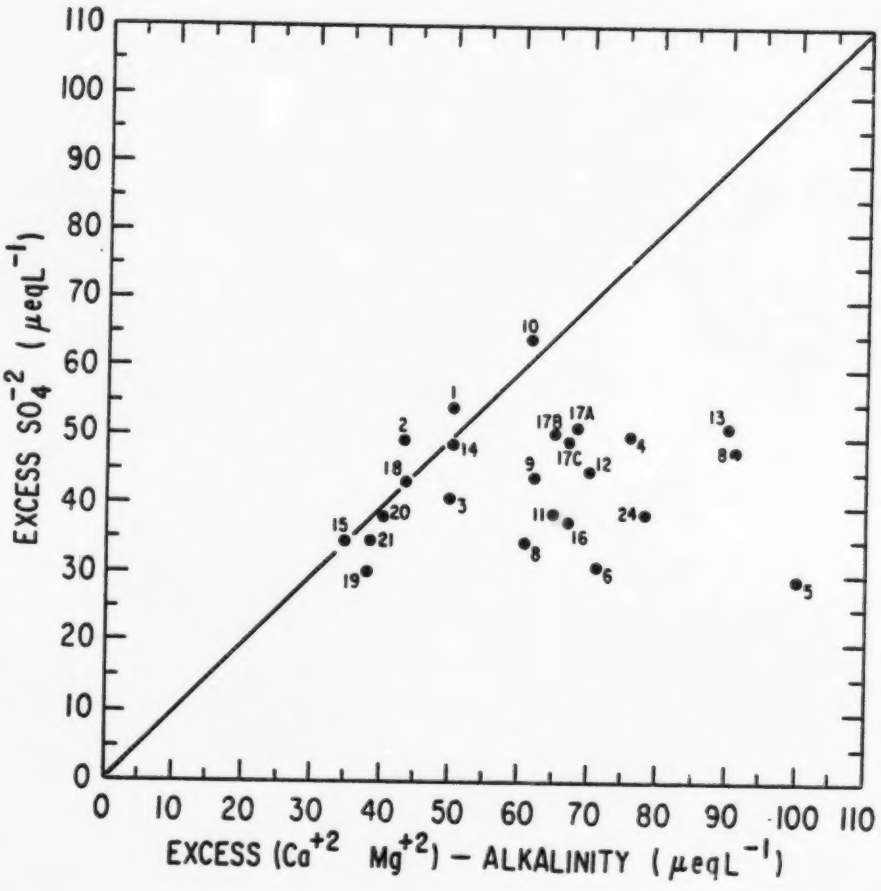

Fig. 2. A plot of non-marine calcium and magnesium minus bicarbonate versus non-marine sulphate for the study rivers. (Numbers correspond to River Key, Fig. 1).

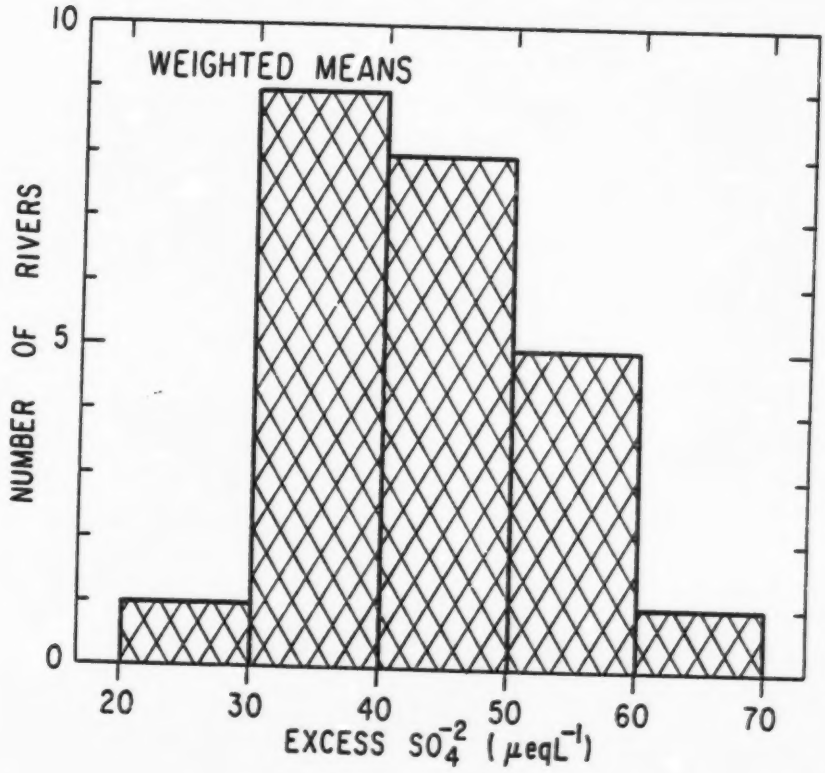

Fig. 3. The distribution of non-marine sulphate values in the study rivers (weighted mean values).

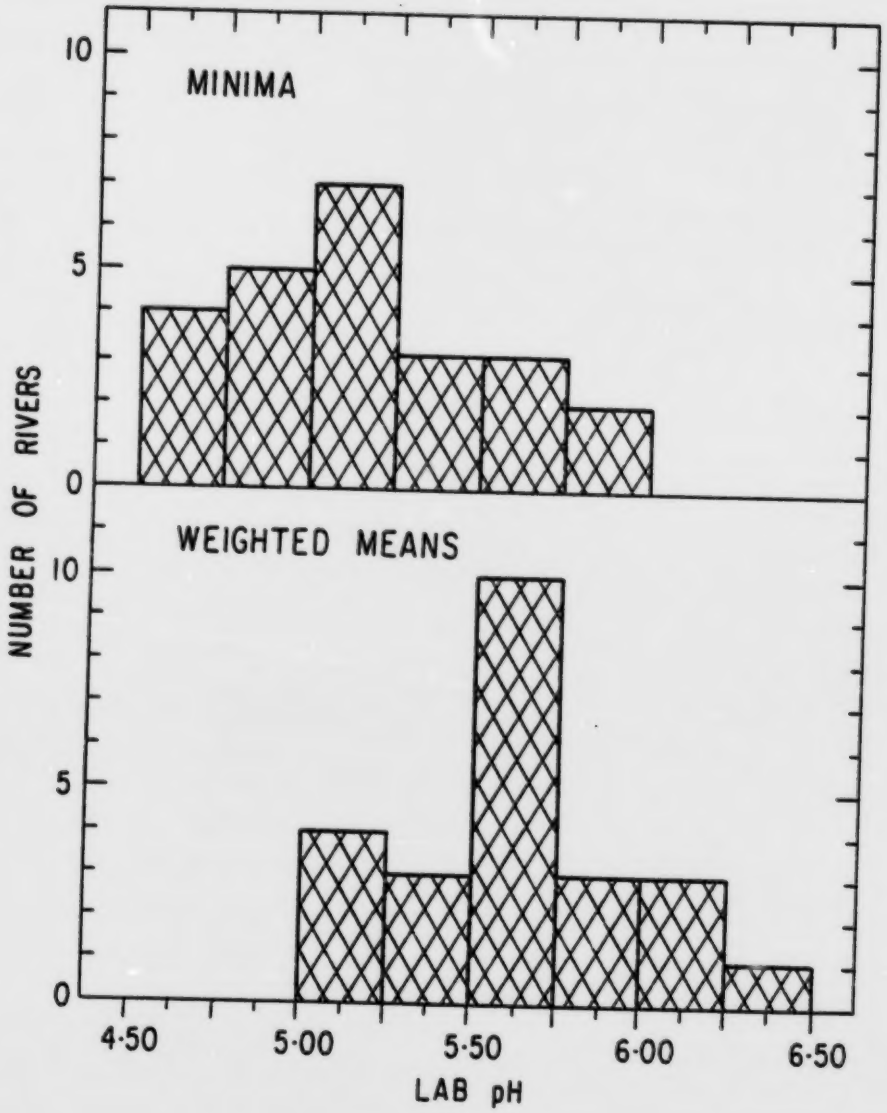

Fig. 4. The distribution of pH values for the study rivers including weighted means and minimas for the study period.

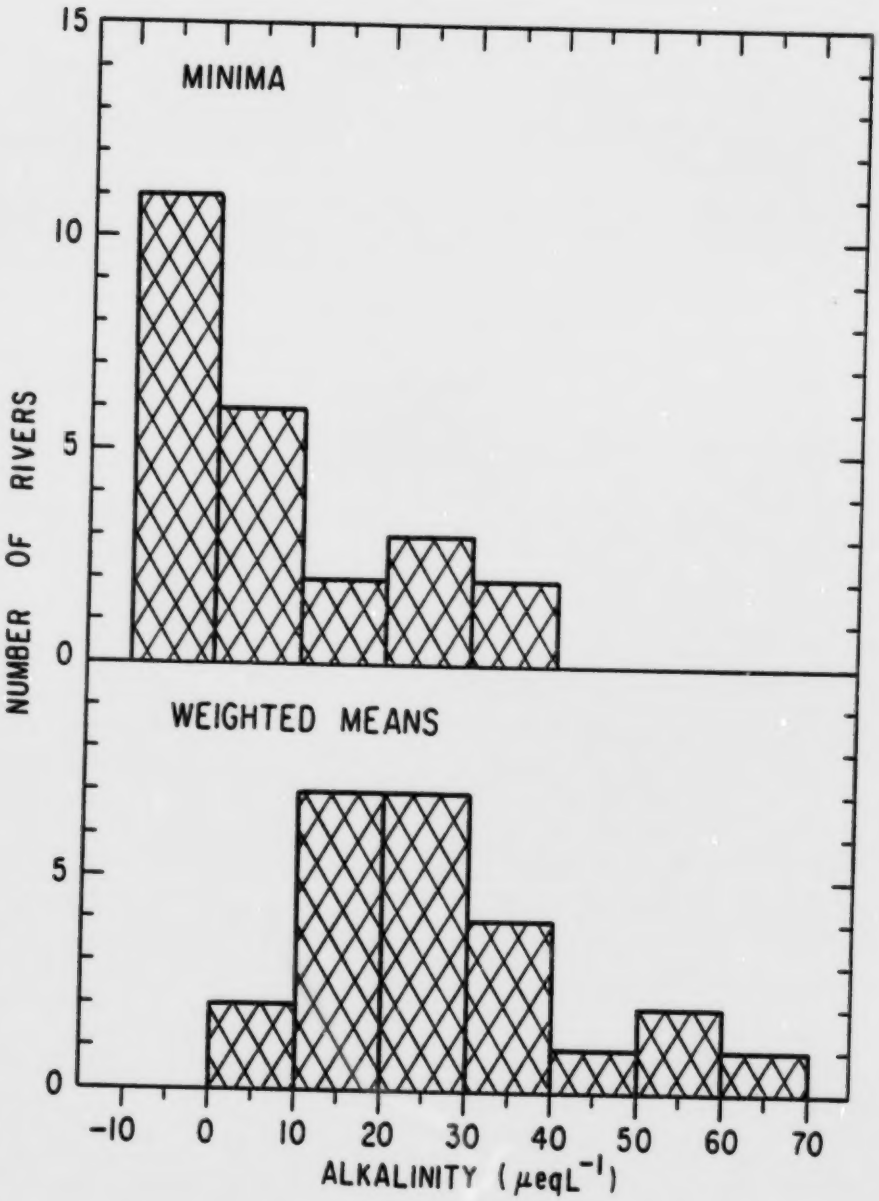

Fig. 5. The distribution of alkalinity values ($\mu eq\ L^{-1}$) for the study rivers including weighted means and minimas for the study period.

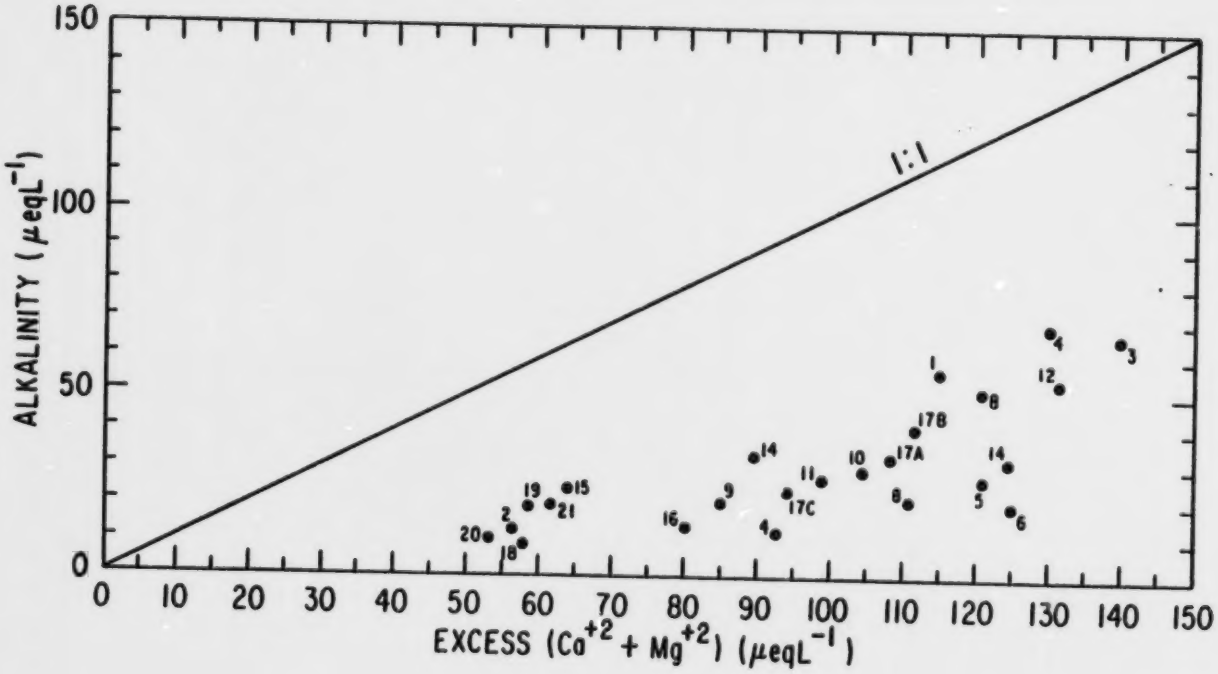

Fig. 6. A plot of the sum of non-marine calcium and magnesium versus alkalinity as an indication of the deficit in alkalinity for the study rivers. (Numbers correspond to River Key, Fig. 1).

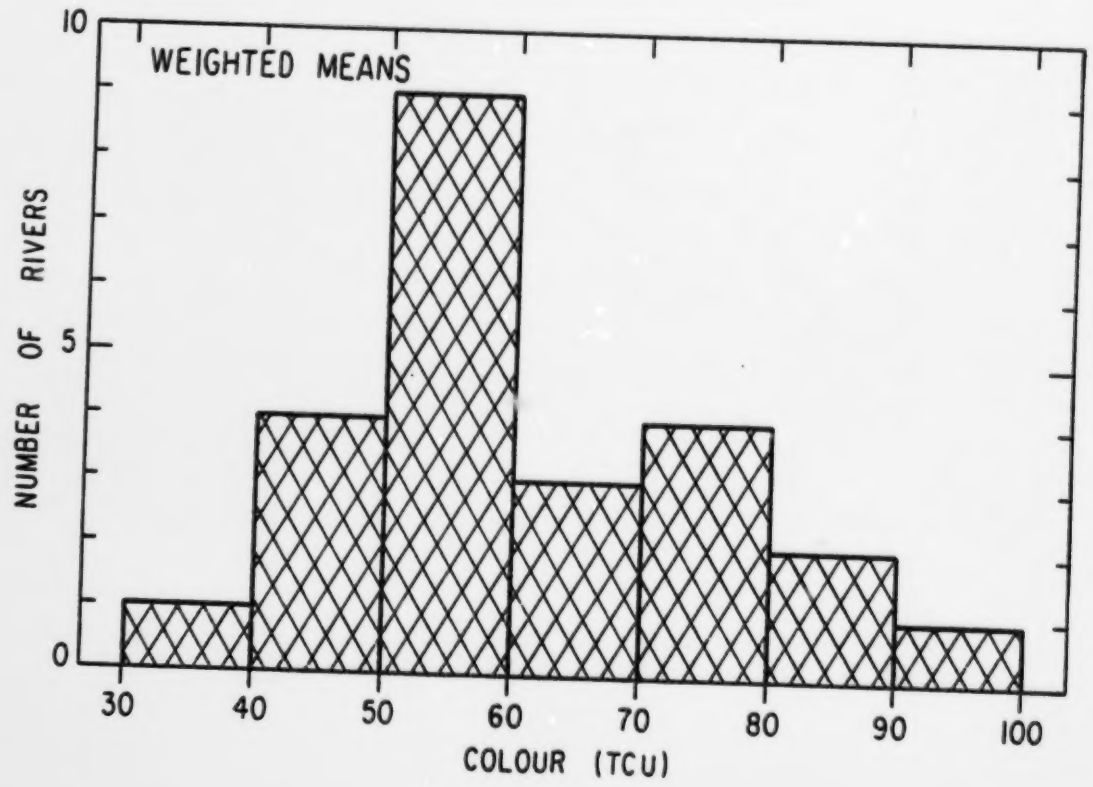

Fig. 7. Distribution of colour values (weighted means) for the study rivers.

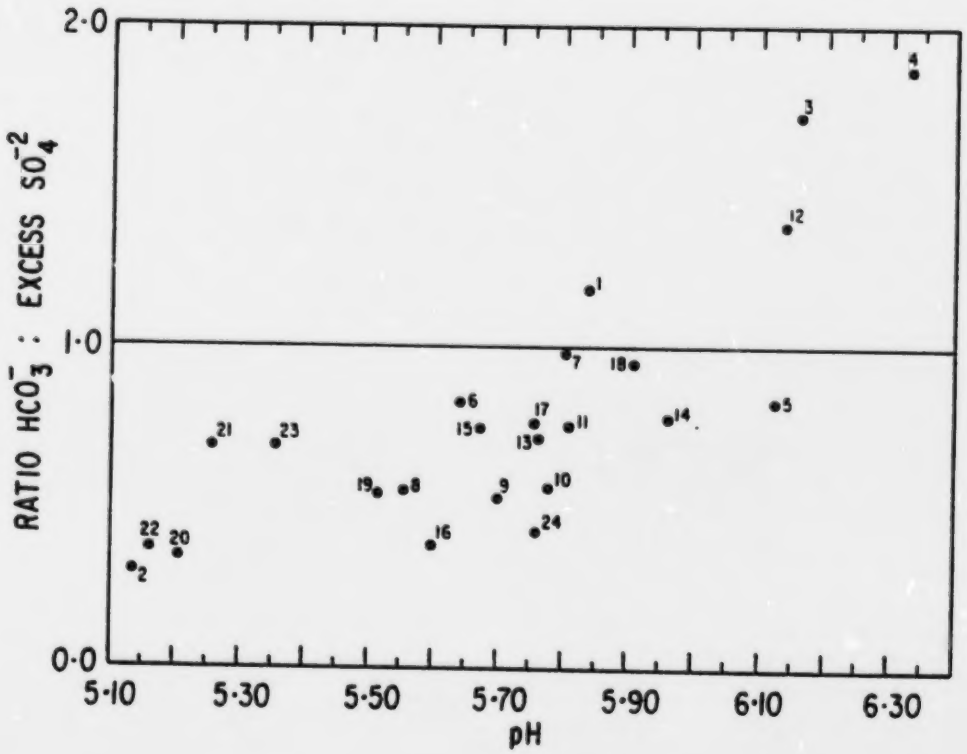

Fig. 8. A plot of the ratio of bicarbonate to non-marine sulphate in relation to river pH. (Numbers correspond to River Key, Fig. 1).

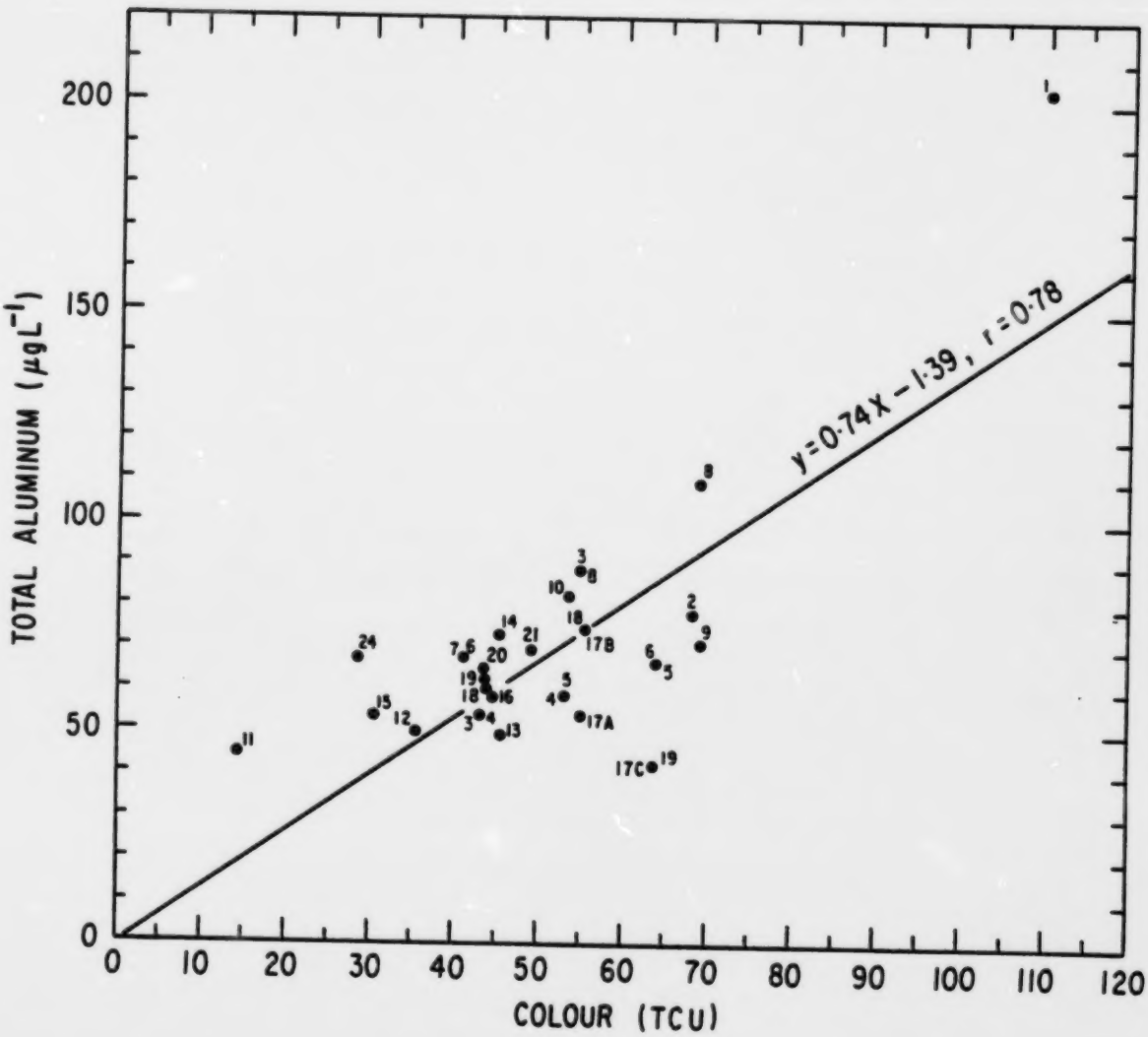

Fig. 9. A plot of total aluminum versus colour for the study rivers. (Numbers correspond to River Key, Fig. 1).

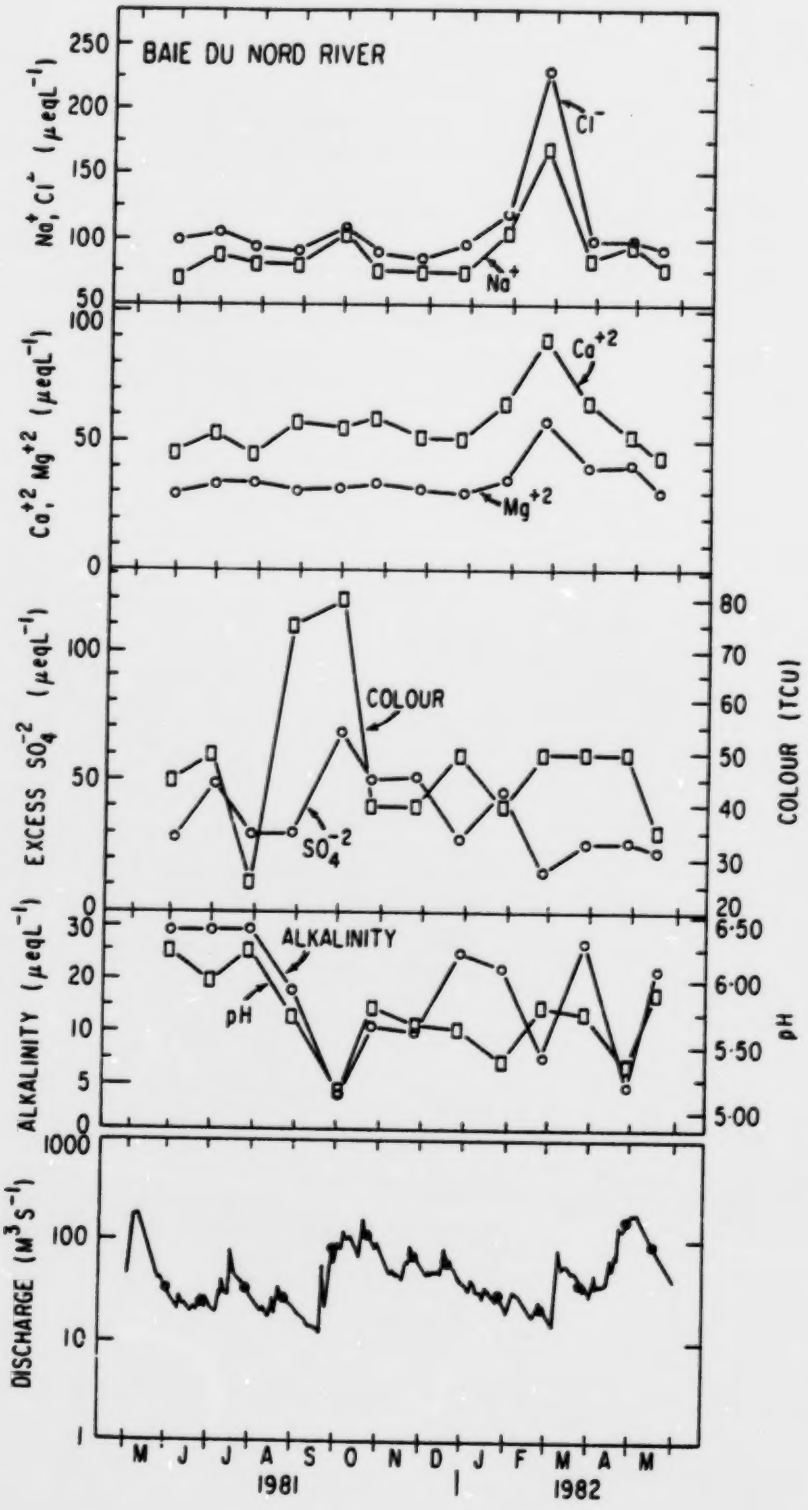

Fig. 10. Temporal variability in key water quality paramaters (pH, alkalinity, colour, sulphate, calcium, magnesium, sodium, chloride) in relation to the river hydrograph for the Baie de Nord River.

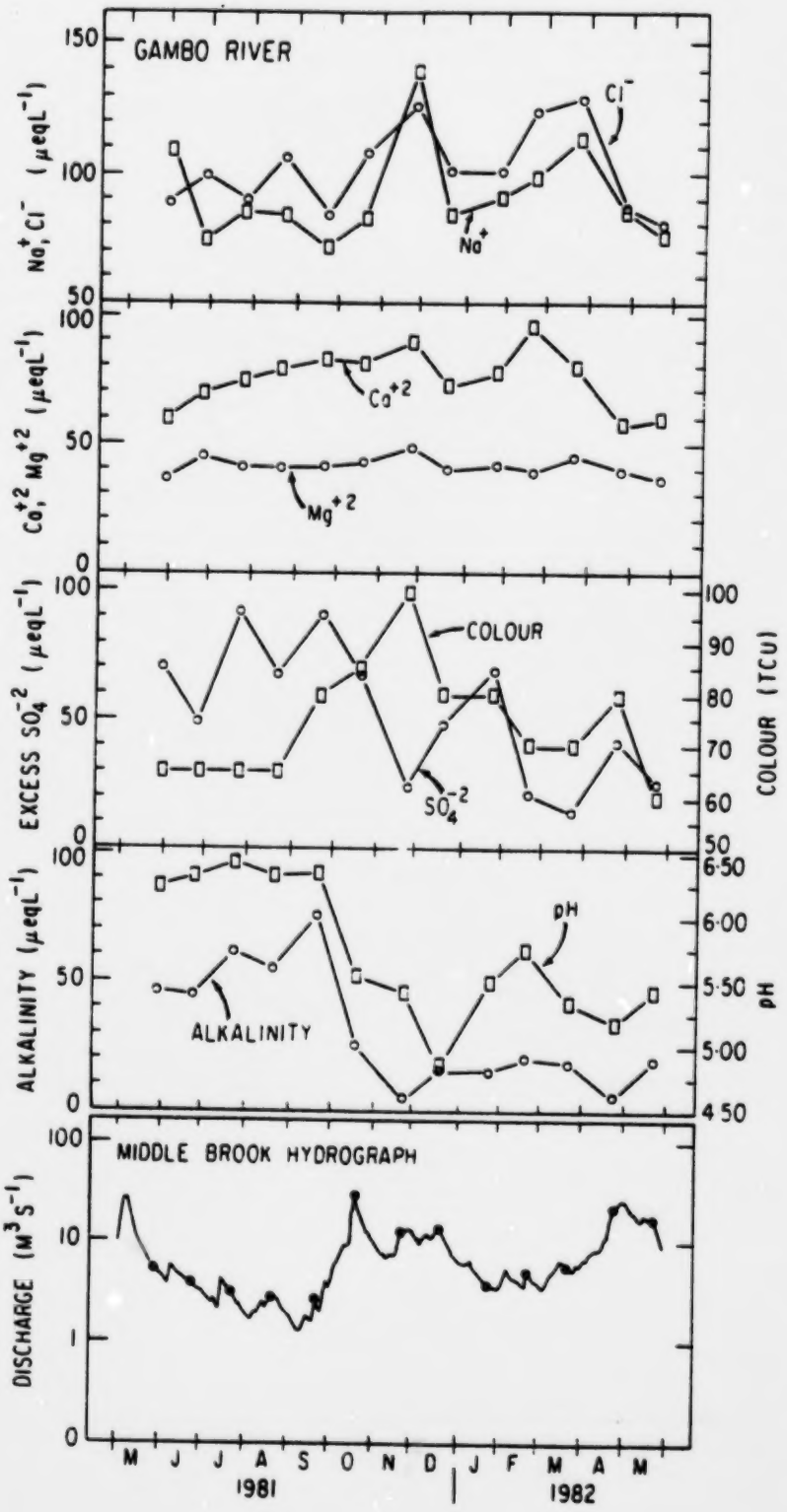

Fig. 11. Temporal variability in key water quality paramaters (pH, alkalinity, colour, sulphate, calcium, magnesium, sodium, chloride) in relation to the river hydrograph for the Gambo River (using the Middle Brook hydrograph).

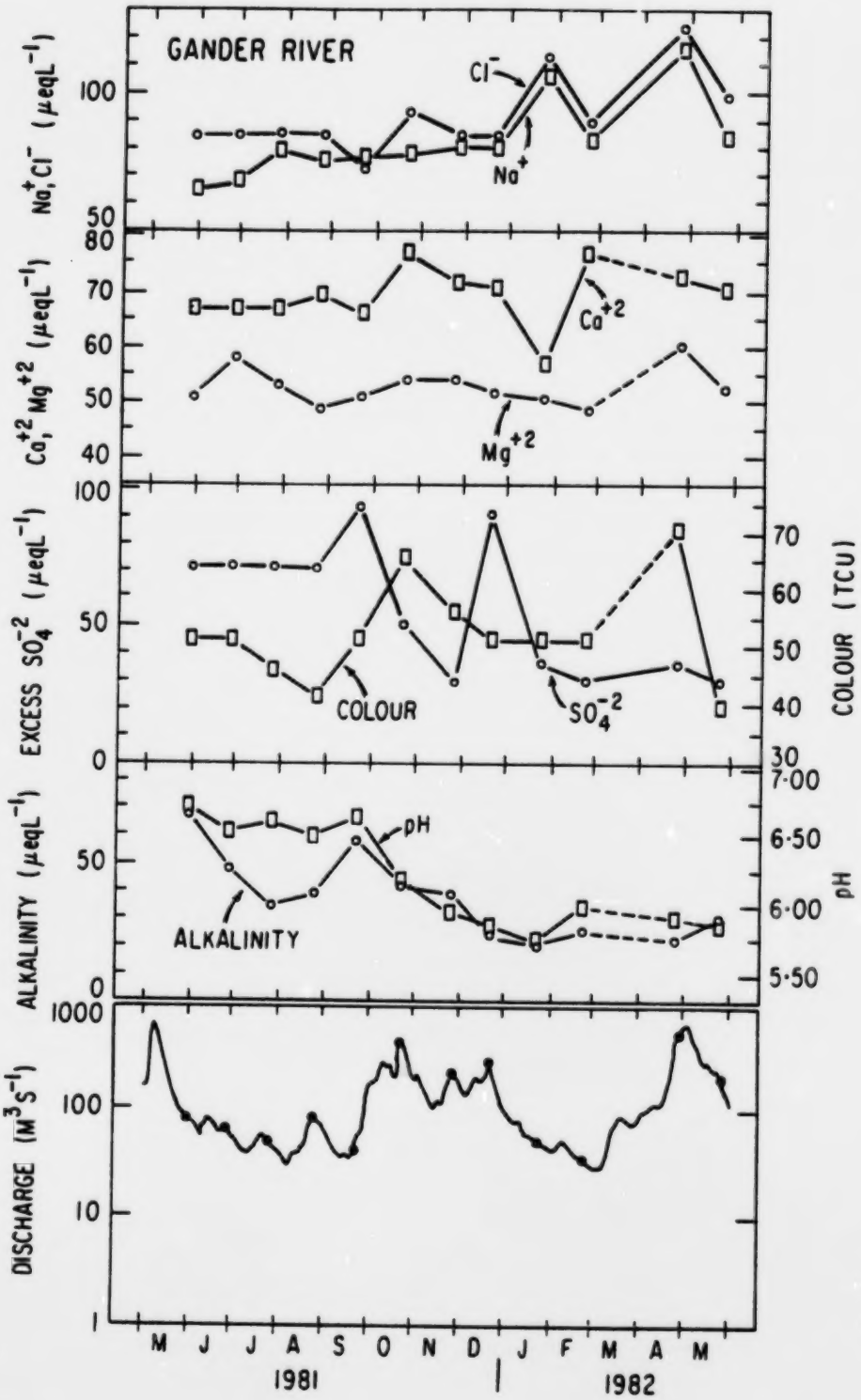

Fig. 12. Temporal variability in key water quality paramaters (pH, alkalinity, colour, sulphate, calcium, magnesium, sodium, chloride) in relation to the river hydrograph for the Gander River.

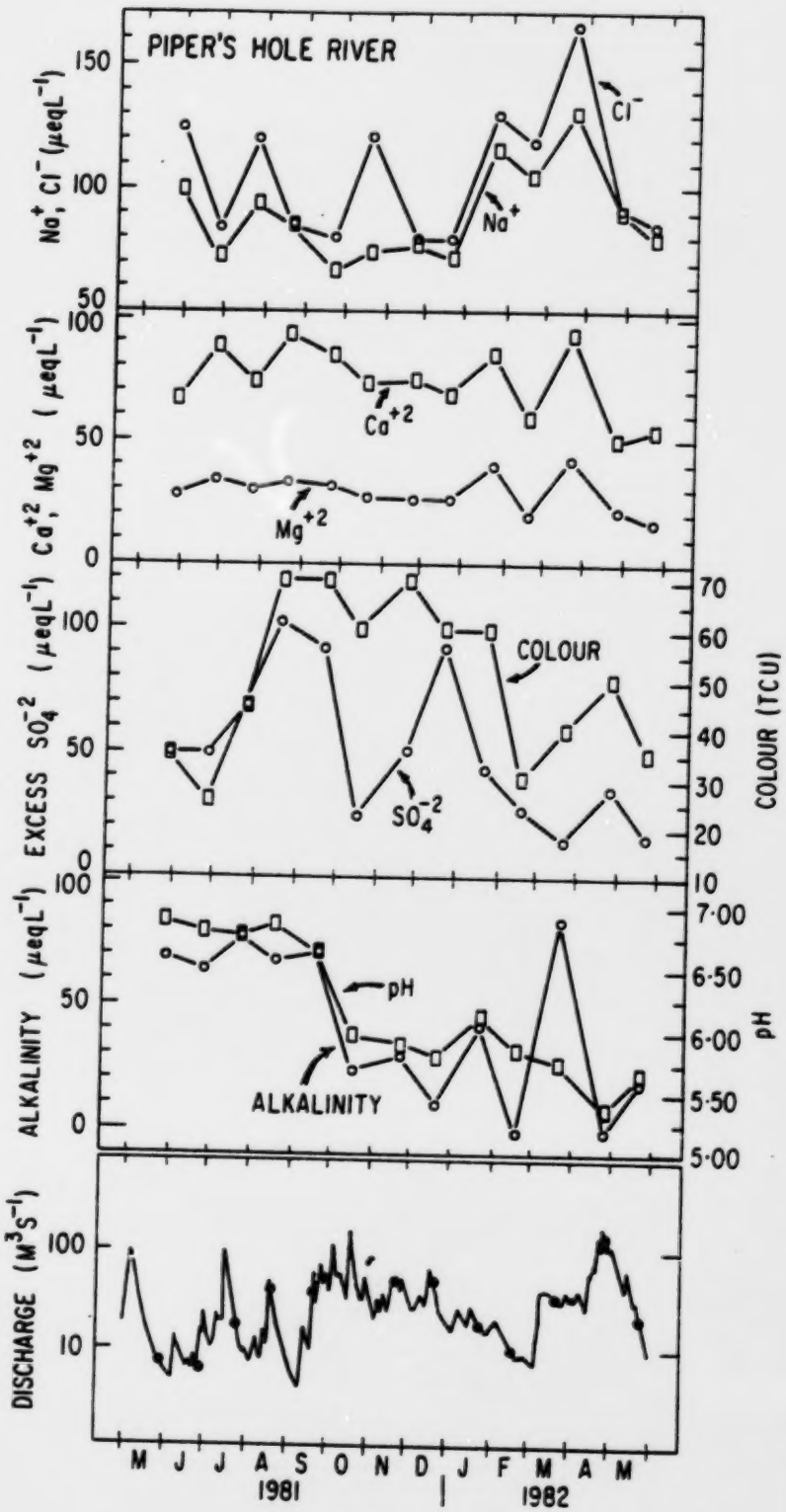

Fig. 13. Temporal variability in key water quality paramaters (pH, alkalinity, colour, sulphate, calcium, magnesium, sodium, chloride) in relation to the river hydrograph for the Pipers Hole River.

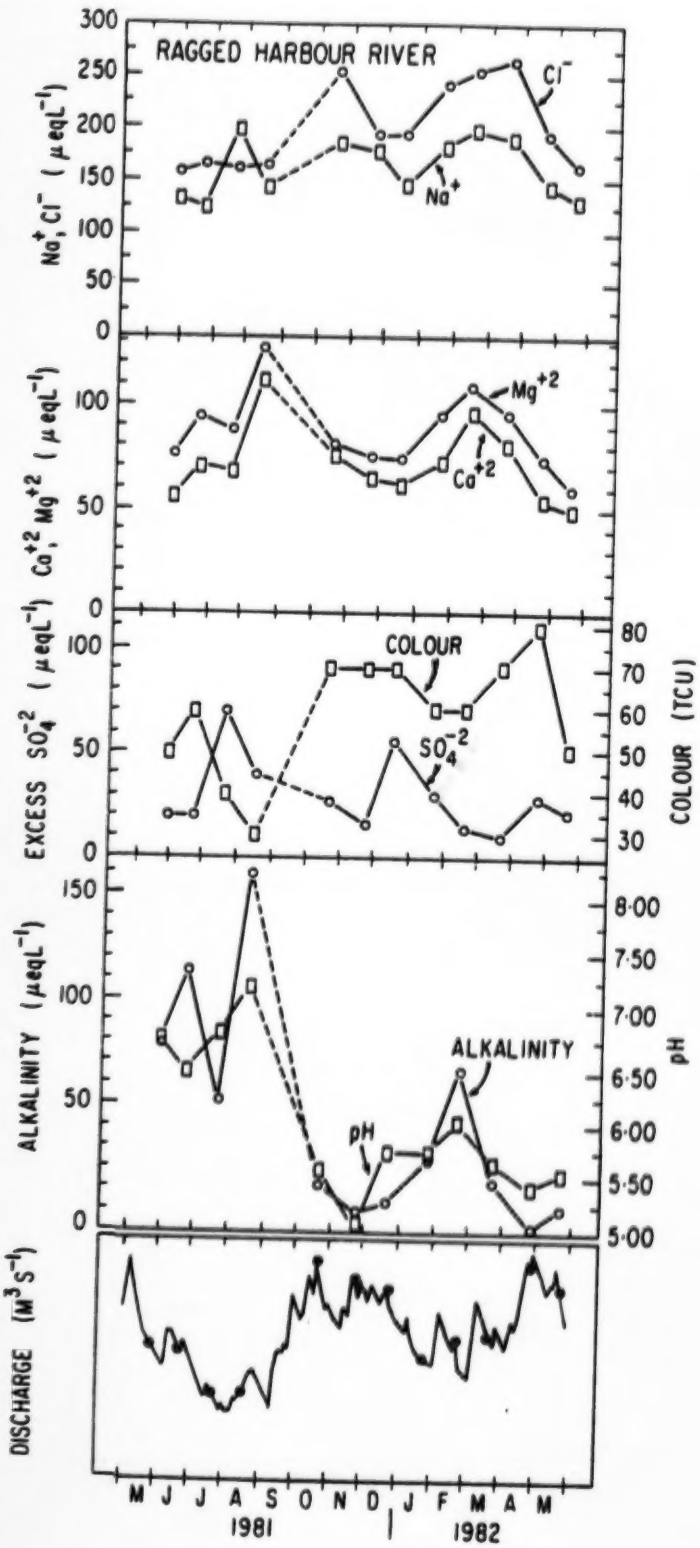

Fig. 14. Temporal variability in key water quality paramaters (pH, alkalinity, colour, sulphate, calcium, magnesium, sodium, chloride) in relation to the river hydrograph for the Ragged Harbour River.

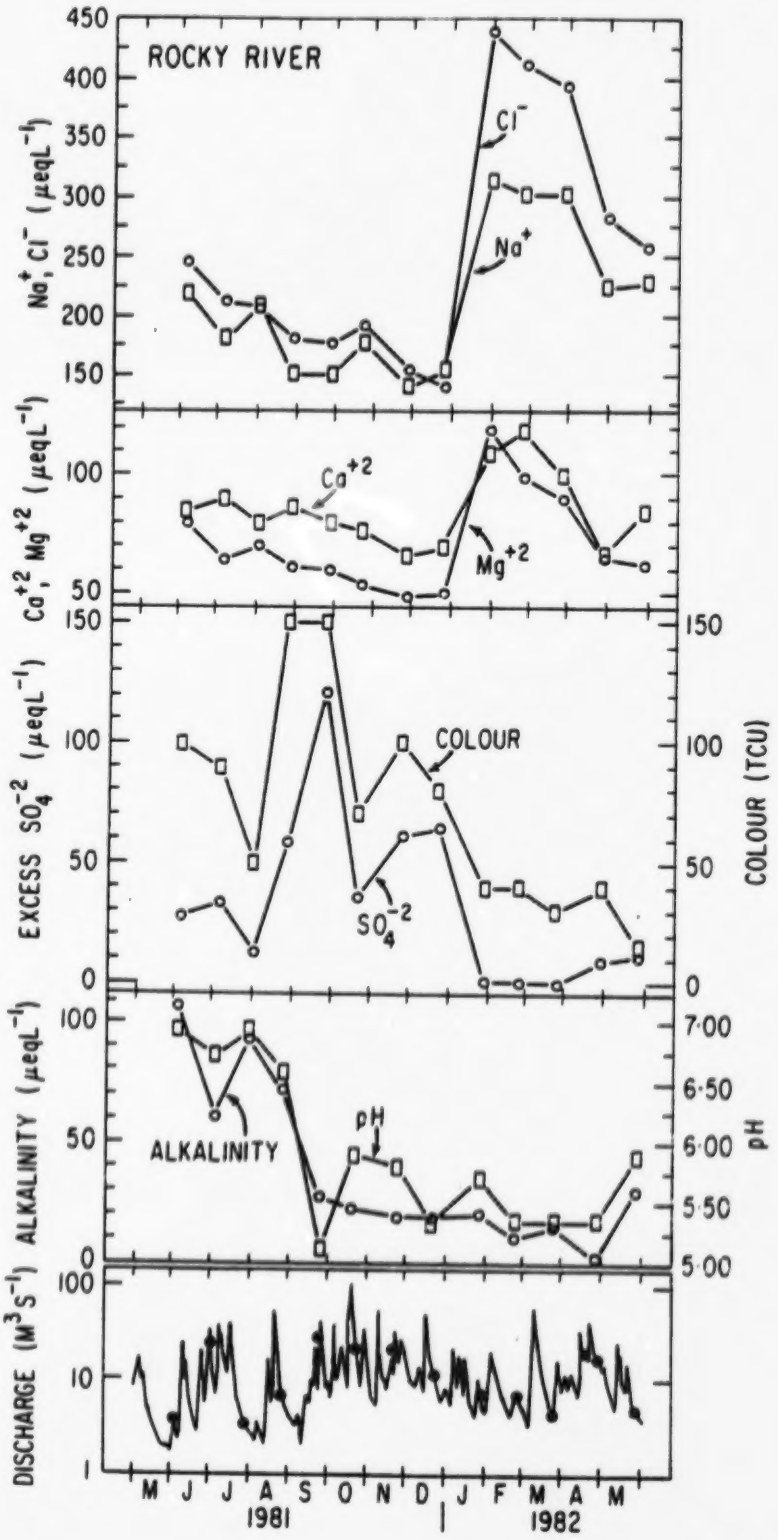

Fig. 15. Temporal variability in key water quality paramaters (pH, alkalinity, colour, sulphate, calcium, magnesium, sodium, chloride) in relation to the river hydrograph for the Rocky River.

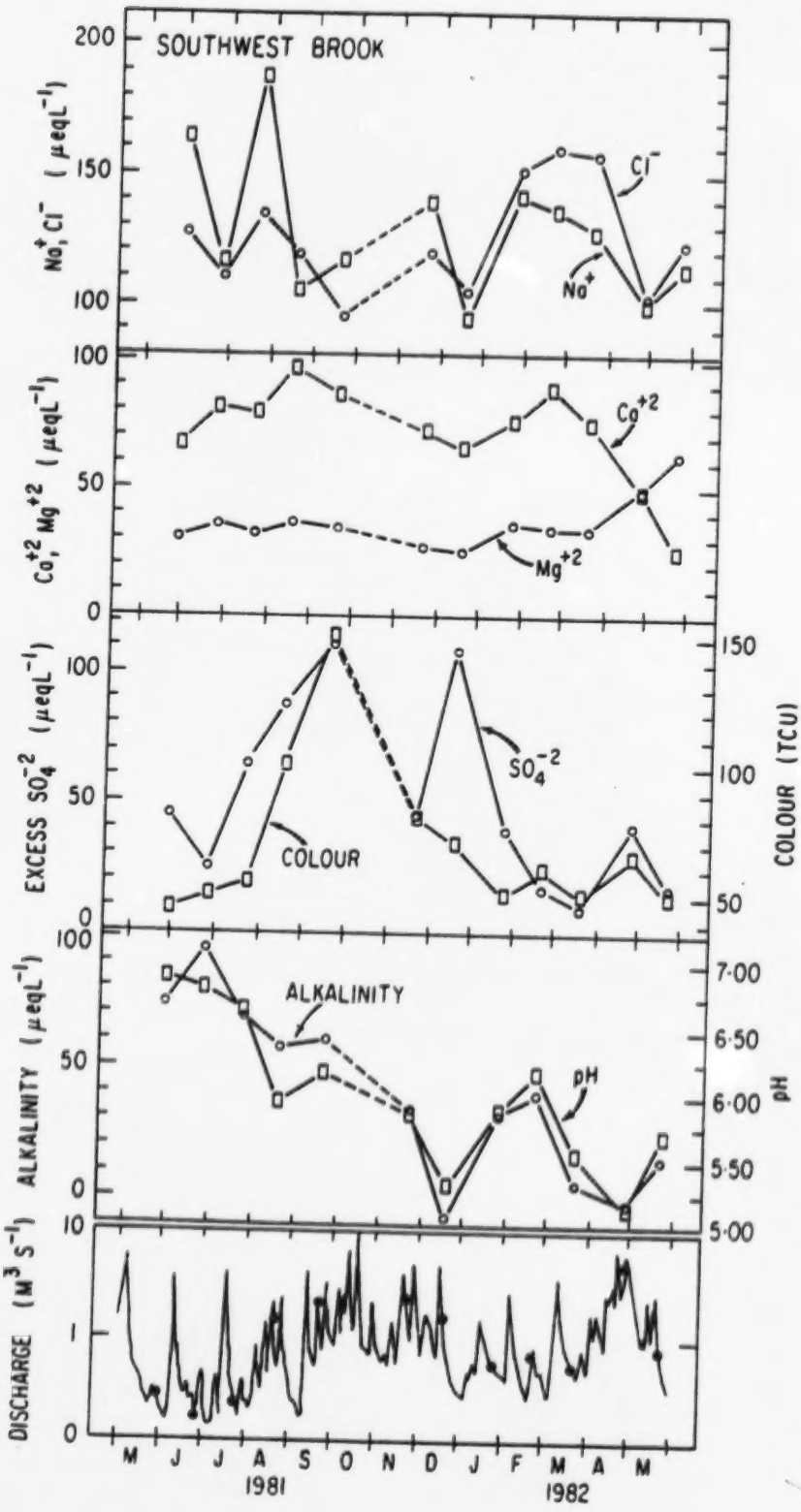

Fig. 16. Temporal variability in key water quality paramaters (pH, alkalinity, colour, sulphate, calcium, magnesium, sodium, chloride) in relation to the river hydrograph for Southwest Brook.

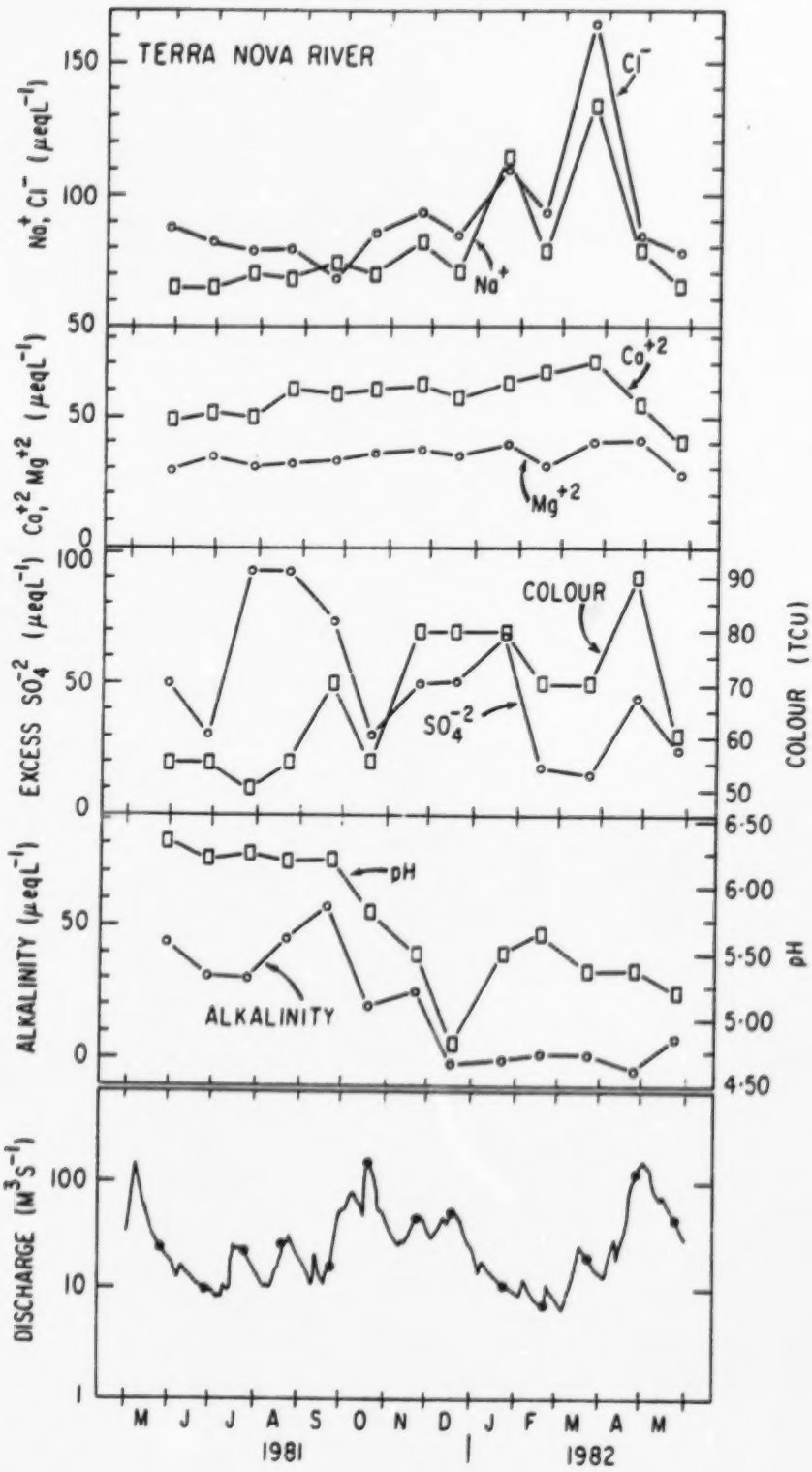

Fig. 17. Temporal variability in key water quality paramaters (pH, alkalinity, colour, sulphate, calcium, magnesium, sodium, chloride) in relation to the river hydrograph for the Terra Nova River.

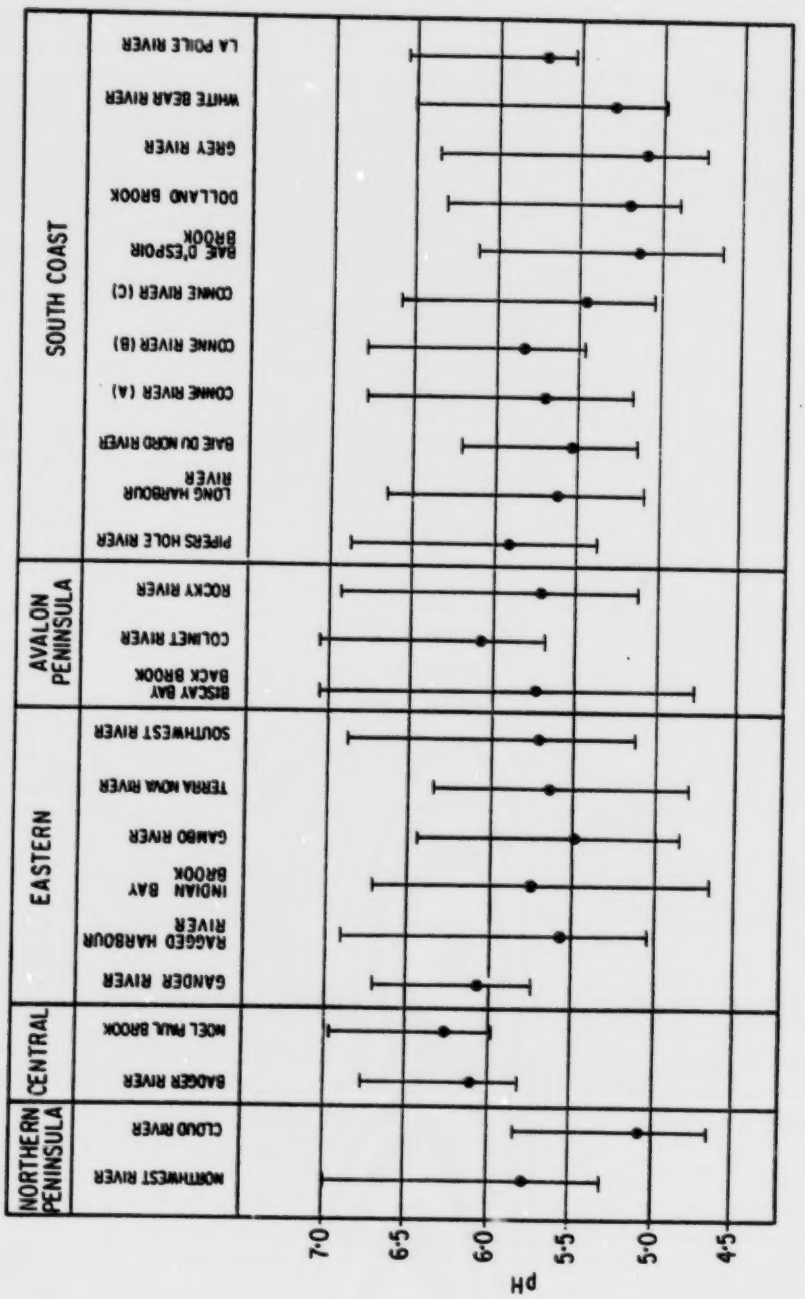

Fig. 18. pH minima, maxima and volume-weighted means for the 22 study rivers (24 sites).

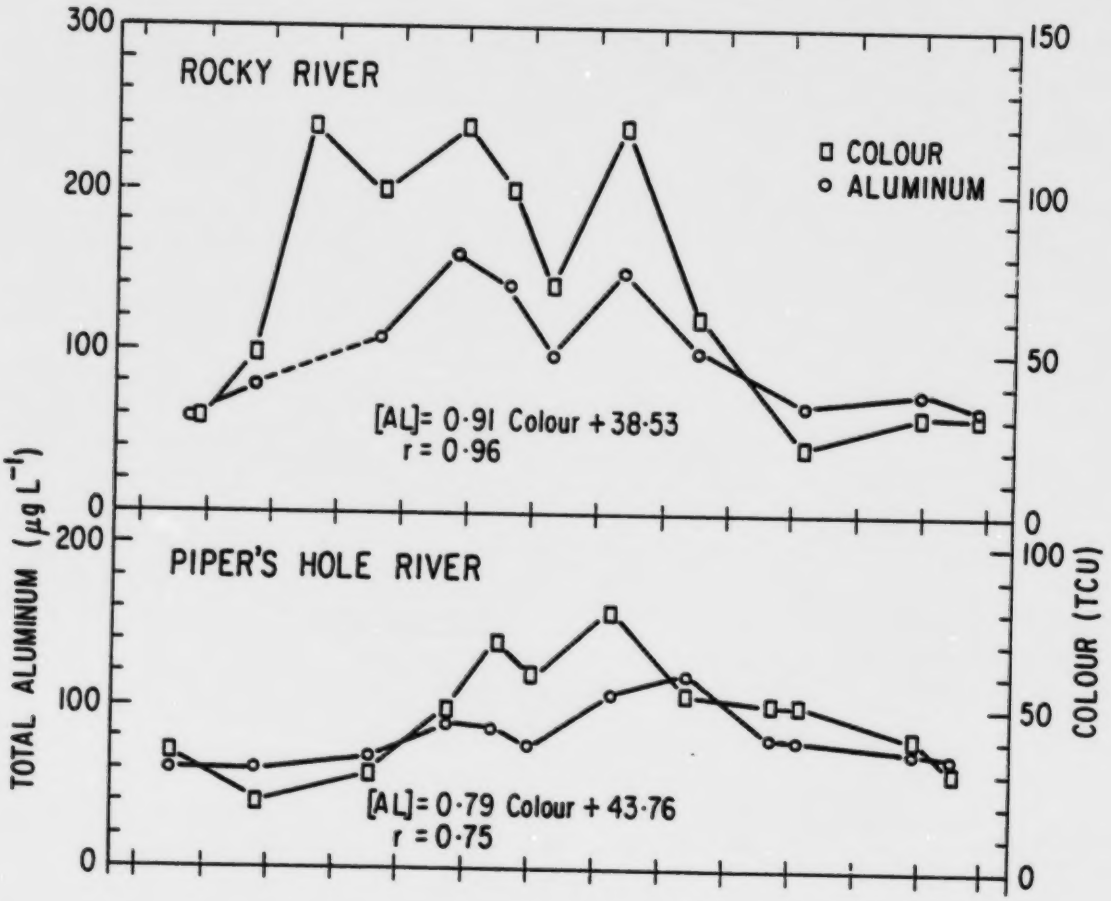

Fig. 19. Temporal variation in total aluminum and colour for Rocky River and Pipers Hole River for the study period (data courtesy of Environment Canada, Water Quality Branch, Moncton, N.B.).

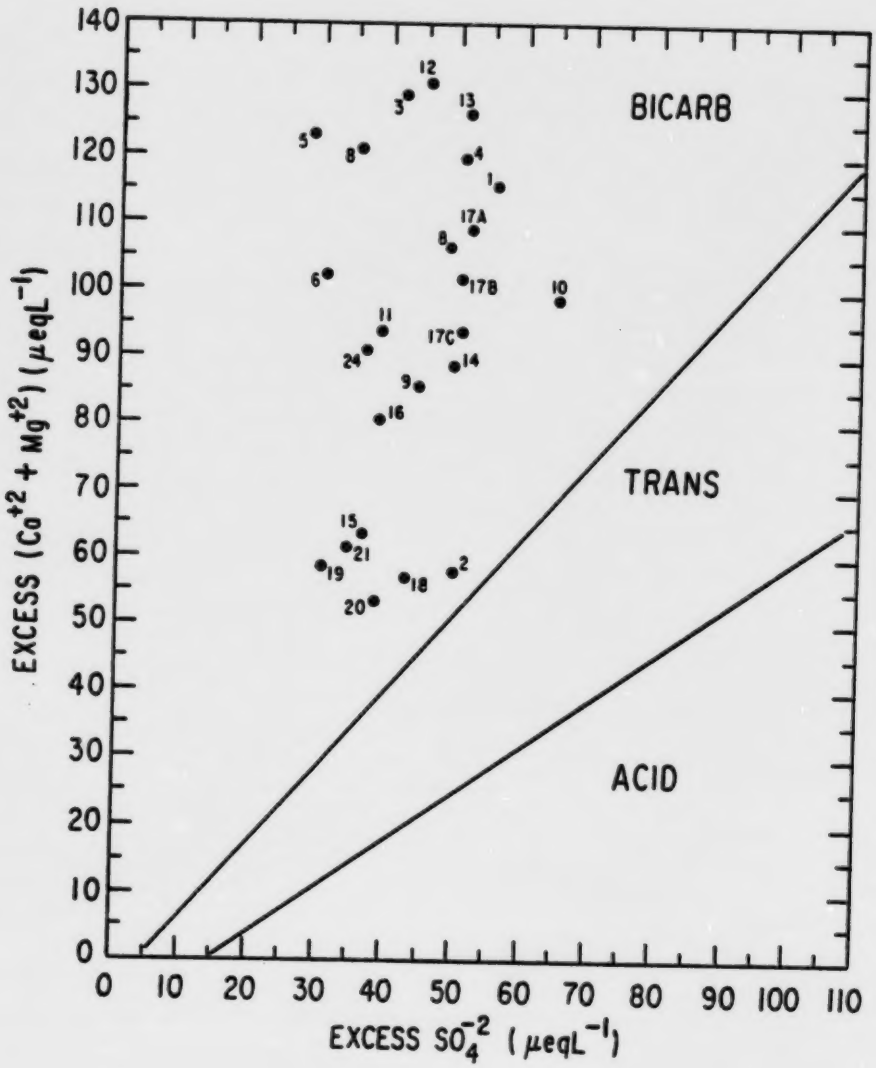

Fig. 20. A plot of data (weighted means) for the study rivers on Henriksen's nomograph (non-marine calcium and magnesium versus non-marine sulphate). (Numbers correspond to River Key, Fig. 1).

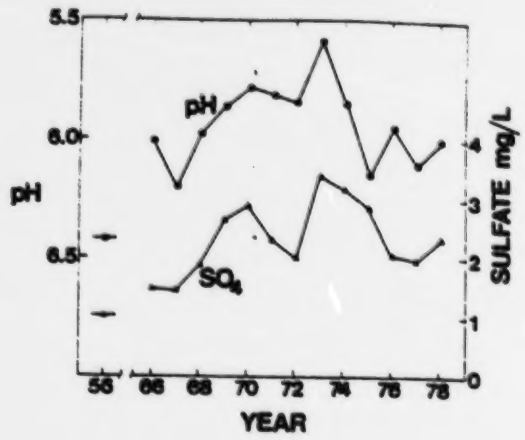

Fig. 21. Annual values for pH and sulphate for the Rocky River, from 1966 through 1978 (after Thompson and Bennett 1981).

APPENDIX I

Monthly water chemistry data, including arithmetic and volume weighted means, for 22 rivers (24 sites) sampled from May 1981 to May 1982.

Table 1.1 - Major physical and chemical parameters with ion balance (as percent difference)

Table 1.2 - Heavy metals and non marine concentrations of selected ions.

*Volume wieghted mean data.

Table 1.1.

	RIVER CODE	DATE	LAB PH	FLD PH	LAB ALK	FLD ALK	CON	TDS	HAR	BIC	CA	MG	NA	K	CL	SO4	SUM CAT	SUM AN	PERC DIFF	SUM CONS	TURB	COL
Northwest Br.	401790	810601	6.11	6.00	26	35	26	41.0	102	43	56	36	68	4	102	104	164	248	-20	14.5	0.8	80
		810625	6.20	7.00	46	69	20	40.0	122	84	74	48	93	4	96	83	218	263	-9	16.8	0.8	90
		810723	6.99	7.11	134	135	20	27.0	179	165	108	72	84	4	99	63	267	326	-10	21.6	0.3	85
		810825	6.43	6.13	55	55	26	33.0	151	67	95	56	84	2	102	104	237	273	-7	17.3	0.4	100
		810922	6.40	6.70	92	115	25	35.0	187	140	118	69	107	4	107	83	299	331	-5	22.2	0.9	100
		811024	6.21	6.09	85	103	15	42.0	194	126	118	76	124	4	135	104	321	365	-6	23.8	0.6	80
		811207	5.30	5.90	8	45	20	33.0	123	55	72	50	93	10	127	42	225	224	0	14.4	0.5	100
		820301	6.49	6.61	91	111	30	37.0	190	135	114	76	114	14	124	44	318	303	2	12.9	0.8	100
		820326	6.28	6.28	122	125	40	53.0	204	152	114	90	109	6	133	38	318	323	-1	21.9	0.8	150
		820426	5.71	5.71	56	70	40	50.0	169	85	95	74	131	7	183	40	307	308	0	19.7	0.8	100
			6.21	6.35	71	86	26	39.1	162	105	96	65	100	6	121	70	267	296	-6	18.5	0.7	90
		*	5.79	6.09	30	54	22	36.5	128	65	76	50	89	6	117	71	221	253	-7	15.9	0.6	91
Cloud R.	401850	810601	5.38	5.35	4	24	25	24.0	43	29	19	18	60	3	85	104	100	218	-37	11.9	0.9	40
		810625	5.58	5.40	8	17	20	22.0	52	21	30	22	71	4	76	63	126	159	-12	9.6	0.5	50
		810723	5.84	5.99	11	20	18	30.0	58	24	33	25	74	4	82	42	135	148	-4	9.2	0.3	40
		810825	5.42	5.27	7	16	23	20.0	72	20	42	30	72	2	79	83	147	182	-11	10.9	0.6	80
		810922	5.46	5.77	10	23	18	13.0	69	28	40	29	77	3	68	42	149	137	4	9.1	0.6	60
		811024	4.98	5.31	-5	-2	48	25.0	67	0	37	30	77	3	119	63	147	181	-10	10.2	0.5	50
		811128	5.68	6.10	15	41	20	24.0	96	50	59	37	93	8	119	42	197	210	-3	10.6	0.5	50
		811207	4.66	5.42	-8	-2	20	32.0	79	0	45	34	86	5	110	42	169	152	5	12.5	0.4	60
		820301	5.64	5.90	16	15	20	20.0	80	18	44	35	88	5	102	38	173	157	5	10.1	0.6	50
		820326	5.59	5.59	24	13	20	31.0	89	16	47	41	89	5	102	35	182	153	9	10.0	0.7	65
		820426	5.42	5.42	18	18	30	42.0	105	22	56	49	114	8	133	35	227	190	9	12.4	0.6	100
			5.42	5.59	9	17	24	25.7	73	21	41	32	82	4	97	53	159	172	-4	10.6	0.6	59
		*	5.08	5.43	0	10	23	27.1	67	14	37	29	77	4	98	63	146	174	-9	11.6	0.6	55
Badger R.	707791	810526	6.69	6.25	66	75	19	30.0	136	91	94	33	64	7	85	63	199	239	-9	15.6	0.7	65
		810623	6.46	6.25	64	78	20	27.0	132	95	94	38	77	6	79	42	215	216	0	14.9	0.6	65
		810721	6.64	6.25	79	90	21	25.0	188	110	86	39	85	7	90	83	217	283	-13	18.3	0.6	40
		810818	6.66	5.50	101	62	21	12.0	146	76	105	41	73	7	71	63	226	209	4	14.6	0.3	50
		810921	6.78	6.78	98	131	17	35.0	146	160	105	42	79	8	68	83	233	311	-14	20.8	0.4	50
		811019	6.26	6.26	71	61	12	18.0	146	74	107	39	74	7	85	42	290	201	18	14.1	0.6	60
		811123	5.85	5.85	49	48	12	40.0	137	59	99	38	75	7	79	42	219	179	10	12.8	0.3	50
		811219	6.12	6.12	46	50	10	26.0	131	61	94	36	72	6	79	42	209	182	7	12.7	0.6	50
		820125	5.93	5.93	44	38	12	36.0	130	46	90	40	87	15	99	63	232	208	5	14.2	0.5	50
		820222	6.12	6.12	49	37	12	26.0	130	45	91	40	88	12	90	40	231	175	14	12.7	0.5	50
		820323	5.82	5.82	50	45	10	22.0	132	55	92	40	89	9	152	40	230	247	-4	15.3	0.4	40
		820427	5.88	5.88	42	24	12	35.0	127	29	86	41	89	7	96	50	223	175	12	12.2	1.0	65
		820525	5.85	5.85	38	35	14	28.0	155	43	81	34	91	7	99	40	213	181	8	12.4	0.3	50
			6.24	6.07	61	60	15	27.7	141	73	94	38	80	8	90	53	226	216	3	14.7	0.5	53
		*	6.11	5.98	54	49	14	27.9	142	60	91	37	81	7	89	47	222	197	6	13.5	0.5	55
Noel Paul's Bk.	707794	810526	6.97	6.60	82	98	21	22.0	127	120	86	38	53	3	56	63	179	238	-14	15.8	0.5	40

	RIVER CODE	DATE	LAB PH	FLD PH	LAB ALK	FLD ALK	CON	TDS	HAR	BIC	CA	MG	NA	K	CL	SO4	SUM CAT	SUM AN	PERC DIFF	SUM CONS	TURB	COL
Noel Paul's Bk.	707794	810623	6.64	5.50	66	82	9	23.0	124	100	83	41	57	4	51	42	185	192	-2	13.5	0.5	40
		810721	6.79	6.15	70	82	22	23.0	105	100	70	35	56	3	42	83	164	226	-16	14.8	0.4	30
		810818	6.66	5.80	101	126	21	24.0	201	154	138	63	57	3	56	83	262	293	-6	20.4	0.6	70
		810921	6.90	6.90	95	101	15	53.0	130	123	89	40	54	3	37	83	186	243	-13	16.4	2.8	30
		811120	5.99	5.99	58	65	20	28.0	144	79	102	43	57	3	51	42	204	172	9	12.6	0.4	45
		811218	6.18	6.18	52	36	20	23.0	131	44	93	38	54	3	62	63	187	169	5	11.5	0.4	40
		820122	6.14	6.14	78	70	20	35.0	131	85	88	43	61	7	65	63	198	213	-4	14.4	0.4	40
		820219	6.35	6.35	86	70	20	26.0	137	85	96	41	67	6	65	19	210	169	11	13.6	0.5	40
		820323	6.13	6.13	84	76	20	32.0	152	93	103	49	61	5	68	38	218	198	5	14.1	0.5	40
		820427	6.16	6.16	68	55	20	33.0	151	67	100	51	61	5	62	50	217	179	10	12.9	1.2	50
		820521	6.00	6.00	59	47	11	3.0	114	57	80	35	63	3	56	29	181	143	12	10.5	0.2	40
			6.41	6.16	75	76	18	27.1	137	92	94	43	58	4	56	55	199	203	0	14.2	0.7	42
		*	6.27	6.08	67	64	17	20.4	134	78	92	42	59	4	57	49	197	184	4	13.0	0.6	44
Gander R.	908610	810528	6.71	6.71	50	68	34	29.0	120	83	67	51	66	7	85	83	191	251	-14	15.9	0.4	50
		810626	6.53	6.53	46	48	15	26.0	125	59	67	58	68	7	85	83	200	226	-6	14.5	0.4	50
		810723	6.60	6.60	66	35	20	28.0	120	43	67	53	79	7	85	83	206	211	-1	13.7	0.6	45
		810820	6.50	6.50	52	39	14	21.0	119	48	69	49	76	7	85	83	201	215	-3	13.9	0.4	40
		810922	6.63	6.63	52	58	14	65.0	117	71	66	51	77	6	73	104	200	248	-11	15.9	0.3	50
		811019	6.18	6.18	51	42	13	22.0	130	51	77	54	78	7	93	63	215	207	2	13.7	0.6	65
		811124	5.96	5.96	42	40	13	27.0	126	49	72	54	81	7	85	42	214	175	10	12.2	0.4	55
		811221	5.87	5.87	38	24	10	22.0	123	29	71	52	81	6	85	104	209	218	-2	13.9	0.3	50
		820125	5.75	5.75	32	22	13	28.0	108	27	57	51	107	11	113	53	225	192	8	13.2	0.3	50
		820223	5.99	5.99	39	26	10	18.0	126	32	77	49	83	7	90	44	216	166	13	11.5	0.4	50
		820427	5.91	5.91	39	23	13	9.0	134	28	73	61	117	7	124	54	259	206	11	13.9	1.2	70
		820525	5.86	5.86	40	31	12	36.0	124	38	71	53	84	7	99	44	215	180	9	12.2	0.4	40
			6.21	6.21	46	38	15	27.6	123	46	70	53	83	7	92	70	213	208	1	13.7	0.5	51
		*	6.07	6.07	44	34	14	22.6	127	42	72	55	89	7	98	65	223	204	4	13.6	0.6	57
Ragged Harbour R.	908820	810528	6.81	6.81	64	79	42	29.0	147	96	56	77	132	7	158	42	271	296	-4	18.8	0.6	50
		810620	6.51	6.00	64	113	10	33.0	166	138	71	95	123	6	166	42	295	346	-8	21.9	0.7	60
		810720	6.88	6.35	80	52	40	25.0	156	63	68	88	198	6	161	83	360	308	8	20.8	0.8	40
		810817	7.21		151	160	40	21.0	240	195	112	128	142	7	166	63	390	424	-4	28.2	0.6	30
		811020	5.58	5.58	21	23	19	36.0	156	28	75	81	185	7	254	63	349	344	1	20.7	0.7	70
		811123	5.05	5.05	10	9	15	42.0	139	12	64	74	177	5	192	42	321	245	13	16.0	0.4	70
		811221	5.76	5.76	24	13	11	34.0	135	16	62	73	145	5	195	83	285	294	-2	17.5	0.5	70
		820125	5.75	5.75	50	28	16	42.0	166	34	72	94	181	14	240	63	361	336	3	20.9	0.5	60
		820222	6.02	6.02	66	62	18	18.0	204	76	96	108	197	10	254	48	411	377	4	24.1	0.8	60
		820323	5.66	5.66	32	23	20	39.0	175	28	80	95	189	7	265	46	371	339	5	20.7	0.6	70
		820427	5.41	5.41	18	1	18	42.0	125	1	53	72	144	6	192	54	274	247	5	15.0	1.3	80
		820525	5.53	5.53	20	11	19	27.0	107	13	48	58	130	5	164	44	241	221	4	13.5	0.3	50
			6.01	5.81	50	48	22	32.3	160	58	71	87	162	7	201	56	327	315	2	19.8	0.7	59
		*	5.57	5.54	24	19	18	36.4	141	23	64	77	161	6	208	57	308	288	4	17.7	0.7	69

	RIVER CODE	DATE	LAB PH	FLD PH	LAB ALK	FLD ALK	CON	TDS	HAR	BIC	CA	MG	NA	K	CL	SO4	SUM CAT	SUM AN	PERC DIFF	SUM CONS	TURB	COL
Indian Bay Bk.	1109490	810528	6.66	6.66	46	56	42	29.0	110	68	57	47	89	5	121	63	198	252	-12	15.5	0.5	40
		810622	6.39	5.40	34	58	15	19.0	108	71	55	53	87	6	127	63	201	260	-13	15.8	0.5	40
		810720	6.49	5.80	42	33	23	18.0	96	40	49	47	151	6	104	83	253	228	5	15.4	0.5	25
		810817	6.70	6.10	47	43	20	7.0	97	52	51	46	89	5	164	42	191	258	-15	14.8	0.3	25
		810922	6.58	6.58	56	61	17	44.0	104	74	54	50	93	5	102	83	202	259	-12	16.1	0.3	30
		811020	6.07	6.07	39	32	13	23.0	112	39	61	51	123	6	135	42	241	216	6	14.1	0.5	30
		811123	4.66	4.66	-16	0	13	52.0	166	0	90	76	157	5	243	83	328	326	0	19.1	0.5	120
		811219	5.12	5.12	14	22	10	23.0	116	27	65	51	115	5	127	42	236	195	9	13.0	0.5	60
		820125	5.92	5.92	36	8	12	25.0	124	9	67	57	131	14	141	63	269	213	12	14.2	0.6	50
		820222	6.05	6.05	35	23	13	24.0	125	28	72	53	122	7	147	38	254	212	9	13.9	0.5	40
		820323	5.86	5.86	98	26	15	29.0	111	32	71	59	131	6	164	35	268	231	7	14.8	0.4	35
		820427	5.62	5.62	38	25	15	35.0	124	31	62	62	117	6	141	48	248	220	6	14.1	1.1	50
		820525	5.84	5.84	24	13	16	23.0	104	16	56	29	107	5	130	42	197	187	3	12.0	0.3	40
			6.00	5.82	38	31	17	27.0	115	37	62	52	116	6	142	56	237	235	0	14.8	0.5	45
		*	5.75	5.69	30	24	16	28.8	118	30	63	51	118	6	144	51	238	225	3	14.3	0.6	50
Gambo R.	1109780	810528	6.26	6.26	30	47	30	25.0	109	57	61	37	110	10	90	83	218	231	-3	15.3	0.7	65
		810626	6.32	6.32	32	45	18	25.0	115	55	70	45	74	10	99	63	199	216	-4	13.8	0.6	65
		810723	6.43	6.43	56	62	23	29.0	118	76	75	42	86	8	90	104	212	270	-12	17.1	0.9	65
		810820	6.33	6.33	49	56	16	28.0	121	68	79	42	84	11	107	83	216	259	-9	16.5	0.4	65
		810922	6.36	6.36	52	76	15	60.0	125	93	83	42	72	7	85	10	204	188	4	17.8	1.2	80
		811020	5.56	5.56	24	26	11	29.0	125	32	82	43	83	16	107	83	223	222	0	14.4	0.6	85
		811124	5.42	5.42	39	5	10	46.0	37	6	89	48	141	14	127	42	292	175	25	13.1	0.6	100
		811220	4.85	4.85	2	16	10	30.0	113	20	73	40	84	10	102	63	206	184	6	12.0	0.6	80
		820125	5.51	5.51	30	17	11	41.0	120	21	78	42	91	13	102	83	224	206	4	13.6	0.7	80
		820222	5.76	5.76	32	21	10	36.0	126	26	96	40	98	11	124	40	244	189	13	12.8	0.6	70
		820323	5.36	5.36	25	19	11	31.0	127	23	81	46	114	10	130	33	250	186	15	12.8	0.6	70
		820427	5.19	5.19	20	5	11	15.0	99	7	58	40	87	10	88	54	196	148	14	10.2	0.8	80
		820525	5.44	5.44	29	20	12	25.0	98	24	61	37	77	7	82	38	183	144	12	9.9	0.7	60
			5.75	5.75	32	32	14	32.3	110	39	76	42	92	11	102	60	221	201	5	13.8	0.7	74
		*	5.49	5.49	26	21	12	29.0	105	26	74	42	92	11	102	60	219	188	8	12.7	0.7	78
Terra Nova R.	1110221	810528	6.35	6.35	34	44	34	18.0	86	54	48	30	65	8	88	63	152	204	-15	12.6	0.8	55
		810626	6.20	6.20	32	32	18	19.0	87	39	52	34	64	8	82	42	158	162	-1	10.5	0.7	55
		810723	6.23	6.23	30	31	20	30.0	81	38	49	31	70	7	79	104	157	221	-17	13.3	0.7	50
		810820	6.19	6.19	32	46	15	22.0	92	56	60	32	68	7	79	104	168	239	-18	14.6	0.4	55
		810922	6.20	6.20	38	57	12	50.0	91	70	58	33	74	6	68	83	171	221	-13	14.1	1.0	70
		811020	5.81	5.81	18	20	11	16.0	96	24	60	36	70	7	85	42	173	151	7	10.0	0.7	55
		811124	5.49	5.49	16	26	12	31.0	99	32	62	37	82	6	93	63	187	187	0	12.0	0.4	80
		811220	4.80	4.80	-2	-2	10	32.0	93	0	57	35	71	5	85	63	169	147	7	9.4	0.7	80
		820125	5.51	5.51	17	0	10	33.0	101	0	63	38	114	11	110	83	225	193	8	12.7	0.7	80
		820222	5.66	5.66	22	2	10	29.0	98	2	67	31	77	8	93	31	183	127	18	8.7	0.5	70
		820323	5.37	5.37	14	2	11	35.0	111	2	71	40	144	6	166	40	261	208	11	13.3	0.7	70
		820427	5.38	5.38	14	-4	10	13.0	94	0	54	40	78	6	79	56	178	135	14	9.1	0.9	90

	RIVER CODE	DATE	LAB PH	FLD PH	LAB ALK	FLD ALK	CON	TDS	HAR	BIC	CA	MG	NA	K	CL	SO4	SUM CAT	SUM AN	PERC DIFF	SUM CONS	TURB	COL
Terra Nova R.	1110221	820525	5.20	5.20	8	2	10	26.0	72	2	44	28	66	7	73	35	145	111	13	7.4	0.5	60
			5.72	5.72	21	20	14	27.2	92	25	57	34	80	7	91	62	179	177	1	11.4	0.7	67
		*	5.64	5.64	17	19	13	24.4	92	23	58	35	75	7	88	56	174	167	3	10.8	0.6	64
Southwest Bk.	1210930	810528	6.89	6.89	62	75	45	25.0	109	91	67	32	165	6	127	63	270	281	-2	18.9	0.7	45
		810626	6.81	6.81	91	96	24	25.0	119	117	82	37	115	6	121	42	240	280	-8	18.4	0.5	50
		810723	6.63	6.63	55	69	23	21.0	112	84	79	33	188	5	135	83	305	303	0	20.4	0.6	55
		810820	5.94	5.94	40	58	15	43.0	134	71	97	37	105	4	119	104	244	293	-9	18.5	0.8	100
		810922	6.17	6.17	43	61	17	79.0	121	74	87	34	117	3	96	125	241	295	-10	18.9	0.9	150
		811124	5.85	5.85	104	34	10	37.0	101	41	73	28	139	4	119	63	244	222	5	14.8	0.6	80
		811220	5.29	5.29	12	-8	10	21.0	91	0	66	26	94	4	104	125	189	229	-10	13.6	0.6	70
		820125	5.87	5.87	38	33	12	31.0	114	40	77	37	142	8	152	63	264	255	2	16.5	0.5	50
		820222	6.17	6.17	58	40	12	30.0	125	49	89	35	137	5	161	40	267	249	3	16.2	0.6	60
		820323	5.55	5.55	22	6	12	24.0	111	7	77	35	128	4	158	33	244	198	10	12.7	0.5	50
		820427	5.13	5.13	5	-2	10	10.0	101	0	49	52	100	5	102	56	206	158	13	10.4	1.0	65
		820525	5.69	5.69	28	17	16	23.0	92	21	64	27	114	5	124	35	211	180	8	11.8	0.4	50
			6.00	6.00	46	40	17	30.8	111	50	76	34	129	5	126	69	244	245	0	15.9	0.6	69
		*	5.72	5.72	42	28	14	32.1	107	36	71	36	118	4	113	81	229	230	1	14.8	0.8	81
Biscay Bay (Back) Bk.	2700220	810601	7.06	7.06	70	42	35	20.0	133	51	63	65	185	6	186	42	320	277	7	18.3	0.5	20
		810701	6.21	6.32	32	35	21	32.0	93	43	43	50	162	4	162	63	259	267	-2	16.7	0.6	55
		810727	6.93	6.93	64	70	26	42.0	110	85	54	56	170	5	175	42	285	302	-3	19.2	0.4	30
		810821	6.20	6.20	34	38	30	17.0	95	46	45	49	149	5	158	83	248	288	-7	17.5	0.3	75
		810923	6.58	6.58	52	73	21	23.0	98	89	45	53	170	5	138	104	273	331	-10	20.9	7.2	50
		811021	5.77	5.77	23	14	18	27.0	95	17	46	49	195	5	192	63	296	271	4	17.0	0.4	50
		811125	5.65	5.65	20	25	15	30.0	83	31	37	45	161	5	161	83	248	275	-5	16.8	0.3	50
		811221	5.21	5.21	12	12	12	23.0	85	15	38	47	175	5	169	63	266	246	4	15.5	0.5	50
		820129	4.78	4.78	-4	-2	28	38.0	195	0	84	110	316	14	423	83	525	506	2	29.9	0.4	40
		820224	5.15	5.15	2	-3	31	40.0	212	0	91	122	335	13	488	69	560	557	0	32.1	0.4	10
		820324	5.22	5.22	34	32	28	42.0	168	39	79	89		7	291	54		384			0.4	5
		820428	5.22	5.22	10	-1	27	28.0	133	0	57	76	265	8	305	52	406	357	6	21.8	1.3	20
		820527	5.63	5.63	20	0	27	31.0	123	0	60	63	239	6	277	52	369	329	6	20.0	0.3	10
			5.82	5.82	28	26	25	30.2	125	32	57	67	210	7	240	66	338	338	0	20.5	1.0	36
		*	5.75	5.76	24	23	22	28.2	112	28	51	61	199	6	220	68	315	315	0	19.2	0.9	44
Collnet R.	2801920	810602	7.06	7.06	90		21	36.0	165	0	92	67	198	8	220	42	364	262	16	17.3	0.5	50
		810702	6.41	6.41	66	70	27	30.0	133	85	76	57	173	6	192	63	312	340	-4	21.4	0.4	50
		810723	6.93	6.93	93	98	28	39.0	150	120	87	63	201	6	175	42	357	336	3	22.9	0.5	40
		810824	6.77	6.77	70	76	27	15.0	130	93	74	55	143	6	158	63	279	313	-6	20.0	0.5	50
		810924	5.82	5.82	40	65	21	39.0	164	79	97	67	165	8	178	125	338	382	-6	24.0	1.0	100
		811022	6.17	6.17	50	43	20	30.0	128	52	75	54	187	6	189	63	322	304	3	19.6	0.3	50
		811126	6.33	6.33	56	57	15	34.0	126	70	74	52	153	6	152	63	285	284	0	18.5	0.3	70
		811222	5.73	5.73	40	42	11	29.0	123	51	71	52	166	6	172	42	295	265	5	17.3	0.5	60

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Collnet R.	2801920	820127	6.07	6.07	45	34	16	38.0	179	42	97	82	234	13	265	63	426	369	7	23.7	4.2	40
		820225	5.96	5.96	61	39	12	44.0	202	48	115	87	281	11	327	56	493	431	7	27.4	7.8	40
		820325	5.94	5.94	55	49	21	41.0	202	60	115	86	268	8	330	54	478	444	4	27.7	0.5	25
		820429	5.78	5.78	33	11	25	35.0	153	13	81	72	226	8	288	54	386	355	4	21.6	1.2	30
		820528	5.69	5.69	41	39	28	35.0	148	48	81	67	249	7	291	46	403	384	2	23.8	0.5	40
			6.20	6.20	57	48	21	34.2	154	58	87	66	203	8	226	59	364	344	3	21.9	1.4	50
		*	6.08	6.08	50	51	20	34.5	150	62	86	64	188	7	207	74	346	343	0	21.8	1.2	62
Rocky R.	2801930	810602	6.94	6.94	94	113	17	44.0	180	138	86	80	220	9	248	63	395	448	-6	28.3	1.0	100
		810702	6.72	6.72	50	61	26	42.0	156	74	91	65	181	6	212	63	343	349	-1	22.0	0.5	90
		810728	6.93	6.93	83	93	33	45.0	152	113	80	71	210	6	209	42	368	364	1	23.8	0.5	50
		810824	6.58	6.58	62	73	26	24.0	150	89	87	62	152	6	181	83	307	353	-7	22.0	0.6	150
		810924	5.12	5.12	2	28	22	44.0	141	34	80	61	151	7	178	146	299	358	-9	21.5	0.8	150
		811021	5.90	5.90	29	23	20	37.0	130	28	77	54	178	6	192	63	315	282	5	18.0	0.3	70
		811126	5.81	5.81	29	20	13	38.0	116	24	67	49	141	5	155	83	262	263	0	16.4	0.5	100
		811222	5.34	5.34	20	19	12	26.0	120	23	69	50	154	5	141	83	279	248	6	16.2	0.7	80
		820127	5.71	5.71	24	21	10	49.0	229	26	109	120	316	13	440	63	557	528	3	31.6	0.4	40
		820225	5.36	5.36	26	12	27	49.0	218	15	118	100	303	10	412	56	531	483	5	29.2	0.5	40
		820325	5.35	5.35	30	16	28	41.0	191	20	100	91	303	8	395	54	502	469	3	28.2	0.5	30
		820429	5.36	5.36	14	0	23	28.0	134	0	67	67	226	8	282	48	367	330	5	20.0	1.2	40
		820528	5.89	5.89	50	31	30	21.0	147	38	85	63	229	7	260	48	383	345	5	21.8	0.3	15
			5.92	5.92	39	39	22	37.5	159	48	86	72	213	7	254	69	378	371	1	23.0	0.6	73
		*	5.71	5.71	27	30	21	37.7	147	37	81	65	190	7	225	83	344	344	0	21.3	0.7	89
Pipers Hole R.	3004160	810528	6.88	6.88	60	70	32	15.0	98	85	67	28	124	5	99	63	224	247	-5	16.4	0.4	35
		810626	6.80	6.80	62	65	20	22.0	121	79	88	33	84	6	73	42	211	194	4	13.7	0.5	35
		810723	6.77	6.77	71	77	22	37.0	104	94	73	31	119	5	93	83	229	270	-8	17.8	0.9	45
		810820	6.85	6.85	61	68	15	27.0	127	83	93	33	84	3	85	125	214	292	-16	18.4	0.5	70
		810923	6.62	6.62	61	72	17	69.0	118	88	85	32	67	4	79	104	189	271	-18	17.0	0.8	70
		811020	5.96	5.96	32	29	10	16.0	100	35	73	27	74	4	121	42	178	198	-5	12.2	0.8	60
		811124	5.90	5.90	36	39	10	32.0	102	48	74	27	77	3	79	63	182	189	-2	12.4	0.4	70
		811220	5.79	5.79	32	11	10	19.0	95	13	69	26	72	3	79	104	170	197	-7	12.1	0.7	60
		820125	6.12	6.12	50	45	10	32.0	124	55	85	39	117	12	130	63	252	247	1	16.2	0.9	60
		820223	5.85	5.85	26	-2	11	19.0	80	0	59	21	104	6	113	44	190	157	10	10.2	0.5	30
		820323	5.75	5.75	64	84	12	32.0	136	102	93	43	131	6	166	40	273	308	-6	13.4	0.5	40
		820427	5.38	5.38	14	-1	10	6.0	78	0	50	27	91	4	90	50	173	140	11	9.2	0.9	50
		820526	5.66	5.66	34	19	11	26.0	72	23	54	17	79	5	85	29	156	137	6	9.1	0.6	35
			6.18	6.18	46	44	15	27.1	104	54	74	29	94	5	99	65	203	219	-3	13.7	0.6	51
		*	5.91	5.91	36	31	12	21.7	98	38	70	29	88	5	100	63	190	201	-1	12.4	0.7	56
Long Harbour R.	3409780	810526	6.60	6.30	34	45	10	16.0	74	55	47	23	79	5	93	21	155	169	-4	10.9	0.5	30
		810623	6.66	5.70	46	43	22	22.0	83	52	58	25	95	6	96	42	185	190	-1	12.5	0.5	40
		810726	6.62	6.51	43	49	22	23.0	78	60	51	26	95	6	93	42	178	194	-4	12.6	0.5	30

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Long Harbour R.	3409780	810819	6.24	6.25	33	39	18	24.0	81	48	56	25	86	4	79	42	171	168	1	11.2	0.5	50
		810926	5.53	5.79	8	22	19	17.0	75	27	50	25	69	5	99	83	149	209	-17	12.2	1.2	70
		811021	5.79	5.85	30	21	20	27.0	69	26	47	22	76	7	79	63	152	167	-5	10.5	0.6	50
		811124	5.57	5.90	15	26	11	28.0	68	32	45	22	77	4	73	83	148	188	-12	11.6	0.5	60
		811220	5.52	5.99	11	25	11	21.0	67	31	45	22	79	4	88	42	150	160	-3	10.1	0.7	60
		820126	5.50	6.31	26	15	30	34.0	107	18	75	32	121	10	141	42	239	201	9	13.2		40
		820225	6.19	6.40	48	46	30	33.0	135	56	93	42	156	10	175	40	301	271	5	17.8	0.6	40
		820326	5.98	6.24	30	27	30	28.0	114	33	76	38	147	7	175	40	269	247	4	15.8	0.7	30
		820428	5.09	5.70	1	9	12	22.0	59	10	33	26	96	6	110	31	160	152	3	9.4	1.0	35
		820517		5.73	20	20	9	33.0	52	24	33	19	78	5	96	29	135	150	-5	9.2	0.4	30
			5.94	6.05	27	30	19	25.2	82	36	55	27	96	6	107	46	184	190	-2	12.1	0.6	43
		*	5.62	5.91	17	22	16	24.3	72	27	47	25	88	5	100	50	165	177	-4	11.0	0.8	47
Baie du Nord R.	3410790	810526	6.21	5.98	20	29	12	15.0	80	35	46	30	70	6	99	42	205	176	8	10.8	0.5	45
		810623	5.98	5.95	20	29	19	19.0	86	35	53	33	88	7	104	63	182	202	-5	126.9	0.5	50
		810726	6.22	6.22	28	29	23	17.0	77	35	44	33	81	6	93	42	164	170	-2	10.9	0.3	25
		810821	5.71	5.71	12	18	32	28.0	88	22	57	31	80	4	90	42	172	154	6	10.0	0.7	75
		810926	5.14	5.29	0	-3	15	30.0	88	0	55	32	103	5	107	83	195	191	1	11.8	1.0	80
		811021	5.79	6.13	21	11	21	14.0	91	13	58	33	76	6	90	63	172	166	2	10.5	0.3	40
		811124	5.66	5.83	13	10	12	26.0	83	12	52	31	75	5	85	63	163	159	1	10.0	0.4	40
		811220	5.62	6.01	14	25	15	24.0	81	31	51	30	74	5	96	42	160	168	-2	10.6	0.5	50
		820126	5.38	6.01	13	22	20	28.0	98	27	64	35	105	11	119	63	312	208	20	13.3	0.5	40
		820225	5.79	5.88	17	5	30	41.0	145	7	88	57	169	9	229	46	323	281	7	17.4	0.5	50
		820326	5.75	6.17	23	27	20	24.0	103	33	64	40	83	6	99	40	192	171	6	11.3	0.4	50
		820429	5.34	6.06	10	0	12	35.0	93	0	52	40	96	6	99	40	194	138	17	9.4	1.1	50
		820517		5.90	22	22	8	18.0	72	27	43	29	78	5	93	35	156	155	0	9.8	0.5	35
			5.72	5.93	16	17	18	24.5	91	21	56	35	91	6	108	51	199	180	4	20.2	0.6	48
		*	5.54	5.91	14	11	16	26.0	89	14	54	35	88	3	99	52	186	165	6	12.4	0.7	51
Conne R. "A"	3613351	810526	6.78	6.59	64	78	17	23.0	135	95	85	40	73	8	93	42	206	230	-5	15.3	0.7	55
		810623	6.64	6.60	72	92	22	41.0	152	112	104	47	81	6	82	83	238	277	-8	18.4	0.5	75
		810726	6.79	6.73	89	99	23	32.0	148	121	100	48	76	6	82	63	229	265	-7	17.8	0.5	60
		810928	5.82	5.90	32	37	20	35.0	156	45	111	45	77	6	107	104	240	256	-3	16.4	0.8	100
		811021	5.63	6.06	26	26	22	26.0	121	32	84	37	64	5	79	83	190	194	-1	12.5	0.3	65
		811124	5.76	6.01	23	27	12	39.0	119	33	82	37	65	5	79	83	189	195	-2	12.6	0.4	100
		811220	5.53	6.20	17	10	13	28.0	111	12	76	35	63	4	85	83	178	180	0	11.3	0.6	80
		820126	5.89	6.28	67	47	30	43.0	155	57	103	52	98	12	124	63	265	244	4	16.3		60
		820225	6.22	6.59	85	74	30	37.0	179	90	117	62	109	8	130	46	296	266	5	18.2	0.4	50
		820326	6.27	6.54	108	70	30	35.0	159	85	108	51	105	7	135	48	272	269	1	17.8	0.7	60
		820429	5.17	5.88	7	16	11	23.0	81	20	52	29	65	6	73	38	152	130	8	8.7	1.2	65
		820517	6.20	6.20	40	40	10	19.0	86	49	59	27	68	6	76	40	160	165	-1	10.9	0.4	45
			6.06	6.30	52	51	20	31.8	133	63	90	42	79	7	95	65	218	223	-1	14.7	0.6	68
		*	5.70	6.10	32	32	17	28.6	115	39	78	37	71	6	87	64	192	190	1	12.4	0.7	71

	RIVER CODE	DATE	LAB PH	FLD PH	LAB ALK	FLD ALK	CON	TDS	HAR	BIC	CA	MG	NA	K	CL	SO4	SUM CAT	SUM AN	PERC DIFF	SUM CONS	TURB	COL
Conne R. "B"	3613352	810526	6.75	6.43	58	68	19	17.0	119	83	77	36	69	7	88	63	190	233	-10	15.1	0.7	55
		810623	6.47	6.55	66	78	21	31.0	141	95	93	48	87	6	85	63	235	242	-2	16.5	0.5	65
		810726	6.79	6.75	82	93	36	37.0	138	113	90	48	72	5	76	63	215	228	-3	16.8	0.5	55
		810928	5.99	6.07	33	34	17	35.0	155	42	109	46	74	6	93	104	236	239	-1	15.5	1.0	150
		811021	5.90	6.30	31	42	23	30.0	130	51	88	42	64	5	79	83	199	214	-3	13.8	0.3	70
		811124	5.93	6.17	35	32	12	29.0	124	39	81	41	65	4	79	83	191	201	-3	13.0	0.4	70
		811220	5.72	6.32	28	25	11	25.0	115	31	76	39	64	4	79	53	183	172	3	11.3	0.6	70
		820126	6.05	6.40	66	51	30	43.0	159	62	107	52	101	12	130	53	271	245	5	16.9	0.6	60
		820225	6.33	6.60	82	76	30	39.0	173	93	114	58	119	12	144	58	304	295	1	19.8	0.7	60
		820326	6.23	6.50	50	53	30	43.0	157	65	106	51	111	9	248	54	277	367	-14	21.0	0.8	70
		820429	5.47	6.12	16	27	11	24.0	96	33	60	36	74	6	76	40	176	149	8	10.2	1.2	60
		820517		6.31	44	44	10	31.0	86	54	57	29	65	6	73	35	157	162	-2	10.8	0.5	40
			6.15	6.38	49	52	21	32.0	133	63	88	44	80	7	104	63	219	229	-2	15.1	0.7	69
		*	5.85	6.26	34	39	17	29.7	121	47	80	40	74	6	92	62	200	201	1	13.2	0.7	71
Conne R. "C"	3613353	810526	6.59	6.60	40	179	15	11.0	115	218	71	31	70	7	90	42	180	350	-32	22.2	0.7	65
		810623	6.22	6.30	62	58	21	34.0	135	71	97	38	86	9	93	63	230	226	1	15.3	0.6	90
		810726	6.35	6.40	43	53	30	30.0	98	65	68	33	72	6	82	42	179	188	-3	12.4	0.3	55
		811021	5.42	5.63	13	15	20	30.0	105	18	75	30	62	6	85	83	173	186	-4	11.6	0.3	80
		811124	5.50	5.80	17	10	16	38.0	118	12	86	31	67	5	90	83	190	186	1	11.8	0.4	100
		811220	5.34	5.90	8	6	9	29.0	93	7	71	28	62	5	85	83	166	175	-3	10.8	0.6	100
		820126	6.05	6.00	56	44	30	45.0	159	54	114	45	104	14	141	104	278	299	-4	19.1	0.6	80
		820225	6.29	6.01	74	64	30	44.0	176	78	123	54	130	14	161	83	320	322	0	21.1	0.6	80
		820326	6.12	5.90	38	42	30	39.0	157	51	110	48	127	9	169	63	293	283	2	18.1	0.7	70
		820429	5.03	5.59	3	13	10	26.0	79	16	53	26	74	6	79	42	160	137	8	9.1	1.2	60
		820517		5.88	19	19	9	19.0	77	23	54	23	65	6	79	44	148	146	1	9.4	0.6	55
			5.89	6.00	34	46	20	31.4	119	56	84	35	83	8	105	66	210	227	-3	14.6	0.6	76
		*	5.46	5.79	17	22	16	29.6	102	27	72	30	75	7	92	63	184	183	1	11.7	0.7	74
Baie D'Espoir Bk.	3614260	810526	5.98	5.68	16	24	12	9.0	61	29	34	22	71	4	88	42	131	158	-9	9.6	0.7	55
		810623	5.90	5.95	18	40	15	39.0	72	49	43	29	79	4	82	83	155	214	-16	13.1	0.4	65
		810726	6.12	6.20	23	25	19	23.0	70	31	43	27	72	4	76	63	180	169	3	10.6	0.4	60
		810819	5.53	5.51	9	46	16	29.0	68	56	42	25	66	3	68	42	136	165	-10	10.6	0.6	65
		810925	5.18	5.28	1	13	15	17.0	75	16	46	28	74	3	79	63	152	157	-2	9.9	0.6	80
		811021	5.13	5.43	-2	10	20	26.0	61	12	36	25	68	3	85	63	132	159	-9	9.4	0.5	50
		811124	5.20	5.40	2	11	12	18.0	63	13	37	26	71	3	79	83	136	176	-13	10.5	0.5	60
		811220	5.08	5.52	-1	6	20	22.0	54	8	31	22	64	2	79	104	120	191	-23	10.8	0.7	50
		820126	5.39	5.95	7	19	30	34.0	96	23	58	38	117	8	158	42	221	223	0	13.6	0.5	40
		820225	5.92	6.33	63	38	20	28.0	106	46	64	42	108	6	127	42	220	215	1	13.8	0.5	50
		820326	5.62	6.04	15	1	30	27.0	96	1	57	40	112	6	135	48	214	185	7	11.6	0.8	50
		820429	4.62	5.30	-10	-3	10	21.0	58	0	30	28	78	5	90	35	141	126	6	7.8	0.9	40
		820517		5.59	7	7	8	10.0	38	9	23	16	58	3	68	27	100	105	-2	6.3	0.3	30
			5.47	5.71	11	18	17	23.3	71	23	42	28	80	4	93	57	157	172	-5	10.6	0.6	53
		*	5.14	5.50	2	11	16	21.8	64	14	37	27	75	2	87	55	143	156	-4	9.5	0.6	51

	RIVER CODE	DATE	LAB PH	FLD PH	LAB ALK	FLD ALK	CON	TDS	HAR	BIC	CA	MG	NA	K	CL	SO4	SUM CAT	SUM AN	PERC DIFF	SUM CONS	TURB	COL
Dolland Bk.	3615270	810526	6.32	5.89	21	31	15	16.0	72	38	45	21	71	3	90	42	141	170	-9	10.4	0.8	50
		810726	6.24	6.31	27	35	21	16.0	72	43	49	23	80	4	88	42	156	172	-5	10.9	0.5	30
		810819	5.58	5.60	12	19	7	28.0	87	23	62	25	70	3	90	63	159	176	-5	10.9	0.7	100
		810925	5.31	5.45	4	7	17	21.0	83	8	57	26	83	3	102	83	168	193	-7	11.6	0.8	70
		811021	5.30	5.55	6	7	20	23.0	66	8	45	21	71	3	85	63	140	155	-5	9.4	0.7	50
		811124	5.25	5.45	3	4	10	21.0	65	5	44	21	70	2	79	83	137	168	-10	9.9	0.5	60
		811220	5.24	5.67	3	18	9	23.0	61	22	42	19	67	2	96	42	130	159	-10	9.4	0.5	50
		820126	5.52	6.12	18	20	30	36.0	107	24	10	36	136	8	175	42	191	241	-12	15.0	0.5	40
		820225	5.81	6.32	70	39	30	26.0	104	48	70	34	109	5	147	42	219	236	-4	14.6	0.5	40
		820326	5.77	6.20	20	27	20	28.0	89	33	59	30	99	5	113	42	193	187	1	12.0	0.8	40
		820429	4.89	5.57	-2	16	11	16.0	62	20	38	23	74	4	79	33	140	132	3	8.5	0.8	45
		820517		5.72	13	13	30	24.0	47	16	32	15	61	3	73	33	111	123	-5	7.6	0.4	35
			5.57	5.82	16	20	18	23.2	76	24	46	24	82	4	101	51	157	176	-6	10.8	0.6	51
		*	5.20	5.65	6	16	15	19.9	66	20	41	22	75	4	86	43	142	149	-2	9.3	0.7	50
Grey R.	3716620	810526	6.36	6.00	24	33	12	12.0	72	40	48	19	63	5	79	42	135	161	-9	10.1	0.8	55
		810726	6.28	6.42	37	39	20	23.0	80	48	57	22	80	4	71	63	163	181	-5	11.8	0.5	45
		810819	5.39	5.40	3	7	29	21.0	70	9	51	19	60	2	62	104	132	175	-14	10.4	0.5	80
		810925	5.51	5.71	11	29	18	19.0	87	35	63	24	77	3	79	63	166	177	-3	11.4	0.1	70
		811021	5.19	5.51	0	19	21	27.0	66	23	48	18	64	3	73	63	159	159	0	9.8	0.4	65
		811124	5.17	5.40	2	13	10	29.0	62	16	44	18	63	2	68	83	126	167	-14	10.0	0.5	60
		811220	5.14	5.59	-1	19	10	18.0	52	23	36	16	59	2	79	42	113	144	-12	8.6	0.6	60
		820126	5.72	6.30	35	58	30	35.0	119	71	85	34	124	9	141	63	251	274	-4	17.6	0.4	50
		820225	6.31	6.58	64	63	30	22.0	135	77	101	35	116	5	119	42	256	237	4	16.2	0.4	40
		820326	5.94	6.48	34	30	30	36.0	110	37	77	32	104	5	113	48	219	197	5	13.0	0.7	35
		820429	4.71	5.53	-4	-2	10	21.0	53	0	34	19	61	4	65	35	118	100	8	6.5	1.6	50
		820517		5.39	8	8	9	15.0	32	10	22	10	49	3	51	29	84	90	-3	5.6	0.4	30
			5.61	5.86	18	26	19	23.2	78	32	56	22	76	4	83	56	160	172	-4	10.9	0.6	53
		*	5.09	5.60	4	9	13	20.9	59	13	40	19	64	4	70	46	128	129	1	8.2	1.0	52
White Bear R.	3717440	810526	6.51	6.10	28	40	15	28.0	80	49	53	22	64	6	85	42	145	175	-9	11.0	0.5	60
		810726	6.44	6.52	42	48	21	29.0	89	59	62	26	95	6	82	63	189	203	-3	13.5	0.4	50
		810819	5.49	5.50	14	14	31	25.0	81	17	57	24	62	3	73	63	146	153	-2	9.6	0.8	80
		810925	5.71	5.91	18	27	20	24.0	100	33	70	30	84	5	96	83	190	212	-6	13.3	0.7	80
		811021	5.29	5.65	9	17	22	30.0	77	21	53	24	71	4	90	83	152	194	-12	11.6	0.4	60
		811124	5.22	5.58	0	15	11	25.0	65	18	44	21	65	3	73	83	133	175	-14	10.5	0.5	55
		811220	5.24	5.73	2	17	9	19.0	59	21	40	19	62	3	76	42	124	139	-6	8.6	0.5	60
		820126	5.79	6.30	46	64	50	31.0	126	78	90	35	110	12	119	63	247	259	-2	17.2	0.5	50
		820225	6.28	6.58	110	90	30	24.0	144	110	102	41	147	9	104	42	299	256	8	18.7	0.3	40
		820326	6.33	6.51	58	61	30	35.0	124	74	87	37	97	7	96	48	227	218	2	14.9	0.5	45
		820429	4.98	5.76	2	13	20	21.0	64	16	40	24	70	6	68	35	140	119	8	8.0	0.8	55
		820517		5.69	14	14	10	23.0	34	17	23	12	46	3	45	29	84	91	-5	5.8	0.3	35
			5.75	5.99	29	35	22	26.2	87	43	60	26	81	6	84	56	173	183	-3	11.9	0.5	56
		*	5.30	5.79	11	20	20	23.3	69	24	45	23	69	5	72	45	142	141	1	9.2	0.7	55

	RIVER CODE	DATE	LAB PH	FLD PH	LAB ALK	FLD ALK	CON	TDS	HAR	BIC	CA	MG	NA	K	CL	SO4	SUM CAT	SUM AN	PERC DIFF	SUM CONS	TURB	COL
LaPolle R.	3818800	810526	6.22	5.81	20	22	12	14.0	51	27	32	17	61	3	73	21	114	121	-3	7.6	0.4	30
		810726	6.40	6.58	43	41	20	14.0	89	50	63	26	84	8	88	42	180	179	0	12.0	0.4	10
		810819	5.90	6.03	11	23	15	21.0	60	28	40	19	57	3	56	63	120	147	-10	9.2	0.4	40
		810925	6.06	6.20	32	37	15	16.0	97	45	68	29	80	4	79	63	182	187	-1	12.3	0.5	50
		811021	5.82	6.10	18	31	25	25.0	86	38	58	28	79	4	107	63	169	208	-10	12.6	0.4	40
		811124	5.69	5.83	12	20	12	25.0	77	24	48	29	83	4	113	83	163	221	-15	12.9	0.4	25
		811220	5.60	6.01	11	0	15	19.0	63	1	40	23	71	3	85	42	137	127	4	7.8	0.4	40
		820126	5.79	6.48	50	59	30	29.0	139	72	100	40	112	10	141	42	262	267	-1	16.9	0.4	20
		820225	6.55	6.22	106	78	40	23.0	214	95	167	47	378	15	186	56	608	338	29	28.3	0.2	5
		820326	6.32	6.55	71	63	30	75.0	159	77	108	51	114	9	121	30	283	2[illegible]	11		0.5	25
		820429	5.52	5.75	10	-1	19	23.0	121	0	73	49	144	7	164	58	272	222	10	14.2	0.8	30
			5.99	6.14	35	34	21	25.8	105	41	72	32	115	6	110	51	226	201	0	13.4	0.4	29
		*	5.70	5.89	17	12	19	22.7	105	16	66	39	119	6	133	56	230	205	4	13.1	0.6	31

Table 1.2.

	RIVER CODE	DATE	LAB PH	DO	(PB) LEAD	(AL) ALUM	(MN) MAN	(CD) CADM	(FE) IRON	(CU) COPP	(ZN) ZINC	(NI) NICK	EX SO4	EX NA	EX K	EX CA	EX MG
Northwest Br.	401790	810601	6.11	10.2	0.1	18.9	0.4	0.150	9.7	0.031	0.031	0.068	90	12	2	54	29
		810625	6.20	11.1									70	40	2	72	41
		810723	6.99	9.1									49	29	2	106	65
		810825	6.43	9.3									90	27	0	93	49
		810922	6.40	10.6									68	48	2	116	62
		811024	6.21	12.6									85	48	1	116	67
		811207	5.30	11.6									24	22	7	70	42
		820301	6.49	12.7									27	45	12	112	67
		820326	6.28			18.2							19	35	3	111	81
		820426	5.71			30.9							14	29	4	91	62
			6.21	10.9	0.1	22.7	0.4	0.150	9.7	0.031	0.031	0.068	54	33	3	94	57
		*	5.79	11.0	0.1	19.7	0.4	0.150	9.7	0.031	0.031	0.068	55	24	4	73	42
Cloud R.	401850	810601	5.38	11.0	0.1	5.6	0.4	0.150	5.0	0.031	0.031	0.068	92	13	2	17	13
		810625	5.58	9.1									52	29	2	28	17
		810723	5.84	9.2									30	28	2	32	19
		810825	5.42	9.0									72	29	0	40	25
		810922	5.46	10.2									32	40	1	39	24
		811024	4.98	12.1									46	12	0	35	22
		811128	5.68	12.8									25	27	6	56	29
		811207	4.66	12.9									26	25	3	43	26
		820301	5.64	15.9									23	31	3	42	29
		820326	5.59	12.6		9.0							21	32	3	45	34
		820426	5.42			11.6							17	40	5	53	41
			5.42	11.5	0.1	8.7	0.4	0.150	5.0	0.031	0.031	0.068	40	28	3	39	25
		*	5.08	11.7	0.1	6.0	0.4	0.150	5.0	0.031	0.031	0.068	49	22	2	35	22
Badger R.	707791	810526	6.69	9.5	0.1	16.7	0.7	0.150	7.9	0.031	0.031	0.068	51	17	5	93	27
		810623	6.46	8.8									31	33	5	92	33
		810721	6.64	8.9									71	35	6	84	33
		810818	6.66	8.3									53	34	5	104	36
		810921	6.78	9.6									74	42	7	103	37
		811019	6.26	11.7									30	27	5	105	33
		811123	5.85	12.3									31	31	5	98	33
		811219	6.12	13.3									31	28	5	93	31
		820125	5.93	12.5									49	32	13	88	34
		820222	6.12	13.4									27	38	11	89	33
		820323	5.82	12.9		8.2							18	5	6	89	30
		820427	5.88	13.1		6.1							37	36	5	84	35
		820525	5.85	11.3		8.6							26	36	5	79	27
			6.24	11.2	0.1	9.9	0.7	0.150	7.9	0.031	0.031	0.068	40	30	6	92	32
		*	6.11	11.4	0.1	8.9	0.7	0.150	7.9	0.031	0.031	0.068	35	32	5	90	31
Noel Paul's Bk.	707794	810526	6.97	11.7	0.1	5.6	0.7	0.150	2.1	0.031	0.031	0.068	55	21	2	85	34
		810623	6.64	9.6									35	29	3	82	38
		810721	6.79	9.0									77	32	2	69	32
		810818	6.66	9.2									76	26	2	137	60

	RIVER CODE	DATE	LAB PH	DC	(PB) LEAD	(AL) ALUM	(MN) MAN	(CD) CADM	(FE) IRON	(CU) COPP	(ZN) ZINC	(NI) NICK	EX SO4	EX NA	EX K	EX CA	EX MG
Noel Paul's Bk.	707794	810921	6.90	9.9									78	33	3	89	38
		811120	5.99	12.1									35	28	2	101	39
		811218	6.18	12.8									54	19	1	92	34
		820122	6.14	13.1									53	24	5	87	38
		820219	6.35	12.5									10	31	5	95	37
		820323	6.13	13.1		8.2							28	24	3	101	45
		820427	6.16	12.9		6.8							41	26	4	99	47
		820521	6.00	11.5		3.0							25	32	2	79	31
			6.41	11.4	0.1	5.9	0.7	0.150	2.1	0.031	0.031	0.068	47	27	3	93	39
		*	6.27	11.7	0.1	4.7	0.7	0.150	2.1	0.031	0.031	0.068	42	27	2	91	38
Gander R.	908610	810528	6.71	13.0	0.1	11.1	0.4	0.150	2.1	0.031	0.031	0.068	72	19	5	65	45
		810626	6.53	11.6									72	21	6	66	52
		810723	6.60	9.7									72	32	5	66	47
		810820	6.50	10.5									72	29	5	68	44
		810922	6.63	9.7									94	36	5	64	46
		811019	6.18	11.0									50	26	5	75	47
		811124	5.96	11.2									30	34	5	71	48
		811221	5.87	12.0									92	33	4	69	46
		820125	5.75	12.5									37	44	8	55	43
		820223	5.99	12.6									31	33	5	76	43
		820427	5.91	12.8		2.6							37	49	4	71	53
		820525	5.86	12.5		5.8							30	29	5	69	46
			6.21	11.6	0.1	6.5	0.4	0.150	2.1	0.031	0.031	0.068	57	32	5	68	47
		*	6.07	11.8	0.1	4.4	0.4	0.150	2.1	0.031	0.031	0.068	51	34	5	70	48
Ragged Harbour R.	908820	810528	6.81	11.6	0.1	5.6	2.5	0.150	11.8	0.031	0.031	0.068	20	44	3	53	66
		810620	6.51	9.1									19	30	3	67	84
		810720	6.88	9.2									70	109	3	65	77
		810817	7.21	9.6									39	50	4	108	117
		811020	5.58	11.1									27	44	2	70	64
		811123	5.05	12.8									15	70	1	60	61
		811221	5.76	13.5									56	37	1	58	60
		820125	5.75	12.5									29	48	9	67	78
		820222	6.02	12.1									13	56	5	91	91
		820323	5.66	13.1		14.3							9	42	2	75	77
		820427	5.41	12.6		2.6							28	37	2	49	60
		820525	5.53	10.5		6.9							21	39	1	45	47
			6.01	11.5	0.1	7.3	2.5	0.150	11.8	0.031	0.031	0.068	29	50	3	67	74
		*	5.57	12.0	0.1	4.7	2.5	0.150	11.8	0.031	0.031	0.068	28	45	2	60	63
Indian Bay Bk.	1109490	810528	6.66	11.0	0.1	11.1	0.7	0.150	5.0	0.031	0.031	0.068	46	21	3	54	39
		810622	6.39	9.5									45	16	4	53	44
		810720	6.49	9.2									69	93	4	47	40
		810817	6.70	9.4									19	0	2	48	35
		810922	6.58	10.8									69	36	3	52	43

	RIVER CODE	DATE	LAB PH	DO	(PB) LEAD	(AL) ALUM	(MN) MAN	(CD) CADM	(FE) IRON	(CU) COPP	(ZN) ZINC	(NI) NICK	EX SO4	EX NA	EX K	EX CA	EX MG
Indian Bay Bk.	1109490	811020	6.07	11.0													
		811123	4.66	11.2									23	48	3	59	42
		811219	5.12	13.1									50	22	0	85	60
		820125	5.92	13.3									24	45	3	62	43
		820222	6.05	13.6									43	53	11	64	47
		820323	5.86	13.5		6.7							17	41	4	69	43
		820427	5.62	12.7		4.7							13	40	3	68	48
		820525	5.84	11.0		6.7							28	39	3	59	52
			6.00	11.5	0.1	7.3	0.7	0.150	5.0	0.031	0.031	0.068	24	35	2	54	20
		*	5.75	11.7	0.1	6.3	0.7	0.150	5.0	0.031	0.031	0.068	36	37	3	59	43
Gambo R.	1109780	810528	6.26	11.2	0.1	22.2	1.5	0.150	10.0	0.031	0.031	0.068	31	38	3	60	42
		810626	6.32	9.7									71	60	8	59	31
		810723	6.43	8.7									49	19	8	68	38
		810820	6.33	9.1									92	36	6	74	36
		810922	6.36	10.5									68	24	9	77	35
		811020	5.56	9.8									92	25	5	81	36
		811124	5.42	10.4									68	23	14	80	36
		811220	4.85	11.6									24	70	12	86	39
		820125	5.51	12.8									48	27	7	71	34
		820222	5.76	13.0									69	34	11	76	35
		820323	5.36	13.2		13.7							22	29	8	94	31
		820427	5.19	12.1		2.3							15	42	7	78	37
		820525	5.44	10.7		10.1							42	38	9	57	35
			5.75	11.0	0.1	12.1	1.5	0.150	10.0	0.031	0.031	0.068	26	32	6	60	32
		*	5.49	11.0	0.1	8.2	1.5	0.150	10.0	0.031	0.031	0.068	53	35	8	74	35
Terra Nova R.	1110221	810528	6.35	11.4	0.1	11.1	0.4	0.150	6.4	0.031	0.031	0.068	48	35	9	72	35
		810626	6.20	9.1									50	17	6	47	25
		810723	6.23	9.4									30	18	6	51	29
		810820	6.19	9.4									93	26	5	48	26
		810922	6.20	10.2									93	24	6	58	27
		811020	5.81	11.0									74	36	5	57	28
		811124	5.49	12.0									30	23	5	58	31
		811220	4.80	11.4									50	30	4	60	31
		820125	5.51	13.0									51	24	4	56	30
		820222	5.66	14.2									68	52	9	61	31
		820323	5.37	13.9		10.8							18	26	6	65	25
		820427	5.38	13.3		2.6							16	51	2	68	28
		820525	5.20	11.7		6.9							45	34	4	52	35
			5.72	11.5	0.1	7.8	0.4	0.150	6.4	0.031	0.031	0.068	25	25	5	43	23
		*	5.64	11.3	0.1	8.3	0.4	0.150	6.4	0.031	0.031	0.068	50	30	5	56	28
Southwest Bk.	1210930	810528	6.89	10.4	0.1	16.7	0.4	0.150	9.7	0.031	0.031	0.068	44	27	5	56	29
		810626	6.81	9.7									45	94	3	64	24
		810723	6.63	8.9									25	48	3	80	29
													65	113	2	76	24

	RIVER CODE	DATE	LAB PH	DO	(PB) LEAD	(AL) ALUM	(MN) MAN	(CD) CADM	(FE) IRON	(CU) COPP	(ZN) ZINC	(NI) NICK	EX SO4	EX NA	EX K	EX CA	EX MG
Southwest Bk.	1210930	810820	5.94	9.7									88	39	2	95	29
		810922	6.17	10.0									112	64	1	85	28
		811124	5.85	12.2									46	73	1	70	20
		811220	5.29	13.3									110	36	2	64	19
		820125	5.87	13.1									41	57	5	74	27
		820222	6.17	13.9									17	48	2	86	25
		820323	5.55	13.8		11.2							11	41	1	74	24
		820427	5.13	12.3		2.8							42	44	3	47	45
		820525	5.69	11.1		5.9							18	45	2	62	19
			6.00	11.5	0.1	9.1	0.4	0.150	9.7	0.031	0.031	0.068	52	58	2	73	26
		*	5.72	11.6	0.1	4.7	0.4	0.150	9.7	0.031	0.031	0.068	65	55	2	69	29
Biscay Bay (Back) Bk.	2700220	810601	7.06	11.0	0.1	5.6	1.1	0.150	3.2	0.031	0.031	0.068	16	82	2	60	53
		810701	6.21	10.2									40	72	1	40	39
		810727	6.93	9.6									17	73	1	50	45
		810821	6.20	9.2									61	61	1	42	39
		810923	6.58	10.3									85	93	2	43	44
		811021	5.77	11.6									36	88	2	42	37
		811125	5.65	12.5									61	71	2	34	35
		811221	5.21	13.6									39	81	2	35	36
		820129	4.78	13.9									25	81	6	75	82
		820224	5.15	13.9									1	64	3	81	89
		820324	5.22	13.5		61.7							14	0	1	73	69
		820428	5.22	12.3		3.4							10	96	2	51	55
		820527	5.63	10.7		4.6							14	86	1	54	45
			5.82	11.7	0.1	18.8	1.1	0.150	3.2	0.031	0.031	0.068	32	79	2	52	51
		*	5.75	11.6	0.1	12.8	1.1	0.150	3.2	0.031	0.031	0.068	38	79	2	47	46
Collnet R.	2801920	810602	7.06	10.1	0.1	5.6	0.7	0.150	61.0	0.031	0.031	0.068	11	76	4	87	52
		810702	6.41	9.6									36	66	2	72	44
		810723	6.93	9.3									17	104	3	84	51
		810824	6.77	8.7									41	55	3	71	45
		810924	5.82	10.0									100	67	5	94	55
		811022	6.17	10.8									36	82	2	71	41
		811126	6.33	12.3									41	68	3	70	42
		811222	5.73	13.1									18	71	2	68	40
		820127	6.07	13.8									26	87	8	91	65
		820225	5.96	13.4									11	99	4	108	65
		820325	5.94	13.9		8.3							8	85	1	108	64
		820429	5.78	12.4		3.2							14	66	2	75	52
		820528	5.69	10.5		4.8							5	88	1	75	47
			6.20	11.4	0.1	5.5	0.7	0.150	61.0	0.031	0.031	0.068	28	78	3	83	51
		*	6.08	11.2	0.1	4.5	0.7	0.150	61.0	0.031	0.031	0.068	45	73	3	82	50
Rocky R.	2801930	810602	6.94	10.2	0.1	5.6	0.4	0.150	13.6	0.031	0.031	0.068	28	82	4	81	63
		810702	6.72	9.3									33	63	2	87	51

	RIVER CODE	DATE	LAB PH	DC	(PB) LEAD	(AL) ALUM	(MN) MAN	(CD) CADM	(FE) IRON	(CU) COPP	(ZN) ZINC	(NI) NICK	EX SO4	EX NA	EX K	EX CA	EX MG
Rocky R.	2801930	810728	6.93	9.5									13	94	2	76	57
		810824	6.58	9.2									58	51	2	84	50
		810924	5.12	10.0									121	52	3	76	49
		811021	5.90	10.9									36	72	3	73	41
		811126	5.81	12.3									62	54	2	64	39
		811222	5.34	13.7									64	74	3	66	41
		820127	5.71	9.0									1	71	4	100	91
		820225	5.36	12.5									0	74	2	110	72
		820325	5.35	13.4		8.2							0	83	1	92	64
		820429	5.36	12.1		4.8							9	69	2	61	48
		820528	5.89	10.0		3.2							12	85	2	79	45
			5.92	10.9	0.1	5.4	0.4	0.150	13.6	0.031	0.031	0.068	34	71	2	81	55
		*	5.71	11.0	0.1	5.2	0.4	0.150	13.6	0.031	0.031	0.068	52	65	3	77	50
Pipers Hole R.	3004160	810528	6.88	10.2	0.1	16.7	0.4	0.150	3.6	0.031	0.031	0.068	49	69	3	65	21
		810626	6.80	9.3									31	43	4	86	28
		810723	6.77	9.3									70	67	3	71	25
		810820	6.85	9.8									113	37	1	92	27
		810923	6.62	8.5									93	23	3	84	27
		811020	5.96	11.1									25	7	2	70	19
		811124	5.90	12.2									52	33	2	73	22
		811220	5.79	13.7									93	28	1	68	20
		820125	6.12	13.7									44	44	9	82	30
		820223	5.85	13.8									28	41	4	57	13
		820323	5.75	13.7		8.0							16	38	3	90	32
		820427	5.38	13.9		2.2							37	41	3	49	21
		820526	5.66	11.2		5.3							17	32	3	53	12
			6.18	11.6	0.1	8.0	0.4	0.150	3.6	0.031	0.031	0.068	52	39	3	72	23
		*	5.91	12.2	0.1	4.0	0.4	0.150	3.6	0.031	0.031	0.068	49	32	2	67	22
Long Harbour R.	3409780	810526	6.60	10.4	0.1	5.6	0.4	0.150	3.6	0.031	0.031	0.068	8	27	4	45	17
		810623	6.66	9.3									28	42	5	56	19
		810726	6.62	9.0									29	43	4	49	20
		810819	6.24	7.6									31	42	2	55	19
		810926	5.53	10.3									70	14	3	48	18
		811021	5.79	11.3									52	32	5	45	17
		811124	5.57	11.4									73	36	2	44	17
		811220	5.52	11.9									29	30	2	43	16
		820126	5.50	13.8									22	58	7	72	23
		820225	6.19	13.8									15	59	7	89	30
		820326	5.98	12.2		9.7							15	50	4	73	26
		820428	5.09	11.9		3.8							16	35	3	31	18
		820517		11.5		5.1							16	25	3	31	13
			5.94	11.1	0.1	6.0	0.4	0.150	3.6	0.031	0.031	0.068	31	38	4	52	19
		*	5.62	11.2	0.1	4.9	0.4	0.150	3.6	0.031	0.031	0.068	36	33	3	45	18

	RIVER CODE	DATE	LAB PH	DO	(PB) LEAD	(AL) ALUM	(MN) MAN	(CD) CADM	(FE) IRON	(CU) COPP	(ZN) ZINC	(NI) NICK	EX SO4	EX NA	EX K	EX CA	EX MG
Baie du Nord R.	3410790	810526	6.21	9.9	0.1	5.6	0.4	0.150	3.2	0.031	0.031	0.068	28	15	4	44	23
		810623	5.98	9.2									48	30	5	51	26
		810726	6.22	9.0									29	29	4	43	27
		810821	5.71	9.2									29	29	3	55	25
		810926	5.14	9.8									68	43	3	53	25
		811021	5.79	10.5									50	26	4	56	27
		811124	5.66	11.2									51	28	3	50	26
		811220	5.62	13.4									28	21	3	49	24
		820126	5.38	14.6									46	39	8	61	27
		820225	5.79	13.8									14	42	4	83	42
		820326	5.75	12.9		9.9							26	28	4	62	33
		820429	5.34	13.8		3.2							26	41	4	50	34
		820517		12.5		6.8							23	27	3	42	23
			5.72	11.5	0.1	6.4	0.4	0.150	3.2	0.031	0.031	0.068	36	31	4	54	28
		*	5.54	11.9	0.1	4.9	0.4	0.150	3.2	0.031	0.031	0.068	38	33	4	52	28
Conne R. "A"	3613351	810526	6.78	7.6	0.1	5.6	0.4	0.150	10.0	0.031	0.031	0.068	29	21	6	83	34
		810623	6.64	8.9									72	35	4	103	42
		810726	6.79	8.3									51	30	4	98	42
		810928	5.82	11.0									89	18	4	109	38
		811021	5.63	11.1									72	20	4	82	32
		811124	5.76	8.8									72	21	3	81	32
		811220	5.53	12.8									72	16	3	75	29
		820126	5.89	13.9									45	29	10	100	44
		820225	6.22	12.4									28	37	5	115	53
		820326	6.27	13.3		10.3							29	30	5	105	42
		820429	5.17	11.9		2.4							27	25	5	50	24
		820517	6.20	10.8		5.5							29	26	4	57	22
			6.06	10.9	0.1	5.9	0.4	0.150	10.0	0.031	0.031	0.068	51	26	5	88	36
		*	5.70	11.3	0.1	4.2	0.4	0.150	10.0	0.031	0.031	0.068	52	23	4	76	31
Conne R. "B"	3613352	810526	6.75	10.0	0.1	5.6	0.4	0.150	5.4	0.031	0.031	0.068	50	21	5	76	30
		810623	6.47	9.5									51	40	5	92	42
		810726	6.79	8.4									52	30	3	88	43
		810928	5.99	11.0									91	23	4	107	39
		811021	5.90	10.9									72	20	4	87	37
		811124	5.93	9.4									72	21	3	81	36
		811220	5.72	13.3									52	20	2	75	33
		820126	6.05	13.2									34	29	9	104	43
		820225	6.33	13.8									38	39	9	111	49
		820326	6.23	12.7		18.6							20	27	4	101	34
		820429	5.47	10.8		3.0							29	32	5	58	31
		820517		11.1		5.8							25	25	4	55	24
			6.15	11.2	0.1	8.2	0.4	0.150	5.4	0.031	0.031	0.068	49	27	5	86	37
		*	5.85	11.1	0.1	5.8	0.4	0.150	5.4	0.031	0.031	0.068	50	26	4	78	34

	RIVER CODE	DATE	LAB PH	DO	(PB) LEAD	(AL) ALUM	(MN) MAN	(CD) CADM	(FE) IRON	(CU) COPP	(ZN) ZINC	(NI) NICK	EX SO4	EX NA	EX K	EX CA	EX MG
Conne R. "C"	3613353	810526	6.59	10.1	0.1	5.6	0.7	0.150	11.1	0.031	0.031	0.068	29	19	6	70	25
		810623	6.22	8.6									50	34	7	95	32
		810726	6.35	8.7									30	26	4	67	27
		811021	5.42	10.6									72	15	4	74	24
		811124	5.50	11.6									71	17	4	84	25
		811220	5.34	5.2									72	15	3	70	22
		820126	6.05	12.3									85	26	11	111	36
		820225	6.29	10.7									61	40	11	119	43
		820326	6.12	12.0		6.2							39	33	6	106	36
		820429	5.03	13.3		3.1							31	30	5	51	21
		820517		12.0		3.9							33	21	5	52	18
			5.89	10.5	0.1	4.7	0.7	0.150	11.1	0.031	0.031	0.068	52	25	6	82	28
		*	5.46	11.1	0.1	3.8	0.7	0.150	11.1	0.031	0.031	0.068	51	23	5	70	24
Baie D'Espoir Bk.	3614260	810526	5.98	11.4	0.1	5.6	0.4	0.150	4.3	0.031	0.031	0.068	30	22	3	32	16
		810623	5.90	9.4									72	33	3	41	23
		810726	6.12	6.2									52	29	2	42	22
		810819	5.53	9.1									32	29	1	41	21
		810925	5.18	10.5									52	31	1	45	23
		811021	5.13	12.3									51	21	2	35	19
		811124	5.20	13.8									72	27	1	36	20
		811220	5.08	13.8									93	20	1	30	17
		820126	5.39	9.4									20	30	5	55	27
		820225	5.92	14.2									24	37	4	62	33
		820326	5.62	13.5		12.3							29	37	3	54	30
		820429	4.62	12.6		4.0							23	28	3	28	22
		820517		12.4		5.3							18	21	2	21	11
			5.47	11.4	0.1	6.8	0.4	0.150	4.3	0.031	0.031	0.068	44	28	2	40	22
		*	5.14	12.0	0.1	5.4	0.4	0.150	4.3	0.031	0.031	0.068	43	27	2	36	21
Dolland Bk.	3615270	810526	6.32	10.4	0.1	11.1	0.4	0.150	5.0	0.031	0.031	0.068	29	21	2	44	15
		810726	6.24	8.3									30	31	2	48	17
		810819	5.58	9.0									50	19	1	60	19
		810925	5.31	10.0									69	26	1	55	19
		811021	5.30	12.0									51	23	1	44	15
		811124	5.25	12.6									72	26	1	43	15
		811220	5.24	14.4									28	13	0	40	13
		820126	5.52	14.3									17	39	5	67	25
		820225	5.81	14.3									21	28	2	67	24
		820326	5.77	12.6		6.4							26	36	3	56	23
		820429	4.89	13.5		4.0							22	30	3	37	18
		820517		12.2		6.0							23	21	2	30	10
			5.57	12.0	0.1	6.9	0.4	0.150	5.0	0.031	0.031	0.068	37	26	2	49	18
		*	5.20	12.6	0.1	5.1	0.4	0.150	5.0	0.031	0.031	0.068	31	27	2	41	17
Grey R.	3716620	810526	6.36	10.8	0.1	5.6	0.4	0.150	5.0	0.031	0.031	0.068	31	19	4	46	14

	RIVER CODE	DATE	LAB PH	DO	(PB) LEAD	(AL) ALUM	(MN) MAN	(CD) CADM	(FE) IRON	(CU) COPP	(ZN) ZINC	(NI) NICK	EX SO4	EX NA	EX K	EX CA	EX MG
Gray R.	3716620	810726	6.28	8.0									53	40	3	56	18
		810819	5.39	9.0									96	26	1	50	15
		810925	5.51	10.6									52	33	1	61	19
		811021	5.19	11.6									52	23	1	46	13
		811124	5.17	12.0									74	25	1	43	14
		811220	5.14	12.3									31	15	0	35	10
		820126	5.72	10.4									43	45	6	82	24
		820225	6.31	13.1									25	50	2	98	27
		820326	5.94	13.2		10.0							32	42	3	75	25
		820429	4.71	14.1		4.8							26	25	3	33	15
		820517		12.3		7.8							22	21	2	21	7
			5.61	11.4	0.1	7.0	0.4	0.150	5.0	0.031	0.031	0.068	45	30	2	54	17
		*	5.09	12.7	0.1	5.5	0.4	0.150	5.0	0.031	0.031	0.068	37	25	3	39	14
White Bear R.	3717440	810526	6.51	11.0	0.1	11.1	0.4	0.150	5.0	0.031	0.031	0.068	29	17	4	51	17
		810726	6.44	8.5									51	49	5	61	21
		810819	5.49	8.5									52	22	2	55	19
		810925	5.71	9.6									70	31	4	68	23
		811021	5.29	11.9									71	21	2	51	18
		811124	5.22	11.2									73	24	2	43	16
		811220	5.24	13.6									31	20	1	38	14
		820126	5.79	13.9									46	44	9	88	27
		820225	6.28	13.5									27	89	7	100	34
		820326	6.33	13.6		6.9							35	43	5	85	31
		820429	4.98	13.1		5.9							26	32	4	39	19
		820517		12.5		6.9							23	21	2	22	9
			5.75	11.7	0.1	7.7	0.4	0.150	5.0	0.031	0.031	0.068	44	34	4	58	21
		*	5.30	12.3	0.1	6.6	0.4	0.150	5.0	0.031	0.031	0.068	35	29	4	44	18
LaPolle R.	3818800	810526	6.22	11.1	0.1	11.1	0.4	0.150	1.1	0.031	0.031	0.068	11	21	2	31	12
		810726	6.40	8.5									29	35	6	61	20
		810819	5.90	9.1									55	26	2	39	15
		810925	6.06	10.2									52	36	3	66	24
		811021	5.82	12.2									48	19	2	56	21
		811124	5.69	12.2									68	20	1	46	21
		811220	5.60	13.0									30	24	1	38	17
		820126	5.79	14.0									22	34	7	97	30
		820225	6.55	9.4									30	275	12	163	34
		820326	6.32	13.7		8.2							13	47	7	106	43
		820429	5.52	14.0		3.4							36	53	4	69	38
			5.99	11.6	0.1	7.6	0.4	0.150	1.1	0.031	0.031	0.068	38	54	4	70	25
		*	5.70	12.9	0.1	4.4	0.4	0.150	1.1	0.031	0.031	0.068	38	45	3	63	30

APPENDIX II

Detailed Characterization of Study Rivers

Table 2.1 - River code, location of river mouth, sampling location, watershed area and slope, and proportional composition of major geological types in each watershed.

Table 2.2 - Biophysical description of study rivers as Land Class Types (mapped at Ecodistrict level)

Table 2.1.

River system	Waldron's river code	Location of river mouth	Sampling loction	Watershed area (km^2)	Slope (m/km)	Bedrock geology type	%
Badger River	0707791	N 48°58'30" W 56°02'00"	N 48°59' W 56°02'	712	4.4	Gabbros, diorites Granites, diorites Mafic volcanics Acid to mafic volcanics	39 26 30 5
Baie d'Espoir River	3614260	N 47°53'22" W 56°10'50"	N 47°53' W 56°11'	285	16.1	Granites, driorites Acid to mafic volcanics	78 22
Baie du Nord River	3410790	N 47°43'50" W 55°26'15"	N 47°45' S 55°27'	1171	5.7	Mafic volcanics Granites, diorites Siltstone, metamorphics	40 40 20
Biscay Bay (Back) Brook	2700220	N 46°47'15" W 53°17'00"	N 46°45' W 53°16	28	12.8	Siltstone, conglomerates	100
Cloud River	0401850	N 50°50'00" W 56°13'15"	N 50°49' W 56°14'	534	12.7	Gneisses, schists Granites	81 19
Colinet River	2801920	N 47°13'10" W 53°33'08"	N 47°15' W 53°33'	158	6.9	Siltstone, conglomerates Siltstone, volanics	48 52
Conne River	3613351	N 57°54'45" W 55°41'40"	N 48°00' W 55°36'	602	7.1	Mafic volcanics Acid to mafic volcanics Granites, diorites	75 14 11
Dolland Brook	3615270	N 47°43'40" W 56°35'10"	N 47°44' W 56°35'	688	7.9	Granites, diorites Sandstone conglomerates Acid to mafic volcanics	87 5 8

Table 2.1. (Cont'd.)

River system	Waldron's river code	Location of river mouth	Sampling loction	Watershed area (km^2)	Slope (m/km)	Bedrock geology type	%
Gambo River	1109780	N 48°45'50" W 54°13'30"	N 48°44' W 54°14'	1152	5.2	Granites, diorites Siltstone, metamorphics	46 54
Gander River	0908610	N 49°15'00" W 54°30'00"	N 49°00' W 54°42'	6398	2.7	Gabbros, diorites Siltstone, metamorphics Granites, diorites Mafic volcanics Acid to mafic volcanics Gabbros Peridotite	5 22 12 28 23 7 3
Grey River	3716620	N 47°41'30" W 57°00'15"	N 47°45' W 56°55'	2394	4.6	Granites, diorites Sandstone, conglomerates	73 27
Indian Bay Brook	1109490	N 49°02'20"	N 49°03'	703	4.4	Siltsone, metamorphics Granites	94 6
La Poile River	3818800	N 47°48'00" W 58°19'20"	N 47°51' W 58°17	588	5.7	Sandstone, conglomerate Acid to mafic volcanics Gabbros, diorites Granites, diorites	25 57 5 13
Long Harbour River	3409780	N 47°49'25" W 54°56'30"	N 47°48' W 54°57'	1002	6.3	Granites, diorites Siltstone, metamorphics	97 3

Table 2.1. (Cont'd.)

River system	Waldron's river code	Location of river mouth	Sampling loction	Watershed area (km^2)	Slope (m/km)	Bedrock geology type	%
Noel Paul's Brook	0707794	N 48°49'13" W 56°18'35"	N 48°32' W 56°37'	106	4.4	Sandstone, conglomerate, etc.	28
						Gabbros, diorites	7
						Acid to mafic volcanics	46
						Granites, diorites	19
Northwest River	0401790	N 50°54'15" W 56°16'30"	N 50°54' W 56°17'	110	24.5	Limestone, dolomites, etc	17
						Granites	28
						Gneisses, schists	56
Pipers Hole River	3004160	N 47°55'00" W 54°16'15"	N 47°55' W 54°17'	781	9.5	Granites	32
						Acid to mafic volcanics	36
						Siltstone, conglomerates	32
Ragged Harbour River	0908820	N 49°25'35" W 54°02'50"	N 49°24' W 54°06'	440	3.5	Mafic volcanics	24
						Siltstones, metamorphics	62
						Garnetiferous granite	14
Rocky River	2810930	N 47°13'05" W 53°33'50"	N 47°12' W 53°35'	296	8.2	Siltstone, conglomerates	100
Southwest Brook	1210930	N 48°17'55" W 54°09'35"	N 48°19' W 54°11'	491	9.3	Siltstone, conglomerates	50
						Acid to mafic volcanics	42
						Granites	8
Terra Nova River	1110221	N 48°40'15" W 50°00'20"	N 48°42' W 54°03'	1883	3.6	Siltstone, metamorphics	63
						Granites	31
						Acid to mafic volcanics	6

Table 2.1. (Cont'd.)

River system	Waldron's river code	Location of river mouth	Sampling loction	Watershed area (km^2)	Slope (m/km)	Bedrock geology type	%
Badger River	0707791	N 48°58'30" W 56°02'00"	N 48°59' W 56°02'	712	4.4	Gabbros, diorites Granites, diorites	39 26
White Bear River	3717440	N 47°46'50" W 57°16'50"	N 47°48' W 57°17'	2027	7.3	Acid to mafic volcanics Granites	17 83

Table 2.2. Percentage of each land class in the study river watersheds.

River System	Productive forest	Softwood scrub	Hardwood scrub	Organics	Freshwater	Soil barrens	Rock barrens	Cleared land
Badger River	65	6		16	12			
Baie d'Espoir River	9	23		24	17	25	3	
Baie du Nord River	18	24		27	17	12	1	
Biscay Bay Back Brook	4	12		11	8	62	1	1
Cloud River	17	45		7	9	19	2	
Colinet River	44	17		16	14	7		1
Conne River	28	28		27	13	3		
Dolland Brook	9	22		21	15	30	4	
Gambo River	49	20		20	9	2		
Gander River	51	17		20	8	3		
Grey River	9	22		22	16	28	3	
Indian Bay Brook	57	20		11	9	2	1	
La Poile River	3	13		10	10	59	4	
Long Harbour River	9	19		23	17	31	1	
Noel Paul's Brook	45	18	1	17	13	6		
Northwest Brook	29	38		8	9	15	2	
Pipers Hole River	9	14		23	18	34	3	
Ragged Harbour River	58	7	1	16	17	1	2	1
Rocky River	44	17		16	14	7		1
Southwest River	21	24		30	11	11	3	
Terra Nova River	35	24		26	10	4		
White Bear River	16	23		20	16	22	7	